EXTENSION OF CONSTRUCTABILITY TO INCLUDE OPERATION AND MAINTENANCE FOR INFRASTRUCTURE PROJECTS

Ehsan Saghatforoush

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Abstract

The concept of constructability integrates individual construction functions and experiences through suitable and timely inputs into the early stages of project planning and design. It aims to ease construction processes to achieve the overall project objectives effectively and efficiently. Similarly, the concepts of operability and maintainability integrate the functions and experiences of operation and maintenance (O&M) into project planning and design. Various studies suggest that these concepts have previously been implemented in isolation of each other, thus preventing optimum results in the delivery of infrastructure projects.

This research aims to develop a model to improve the effectiveness and efficiency of operability and maintainability of multi-faceted building projects by extending the constructability concept to include O&M phases, using the case study research strategy focusing on health infrastructure. It firstly discusses the need to extend the concept of constructability by incorporating O&M into the provision of multi-faceted building projects. It then investigates the O&M concerns, and assesses their association with constructability principles, followed by a search for current practices and the principles that can positively affect implementation of operability and maintainability concepts. This provides a structure to develop the extended constructability model that also includes O&M concerns, and maximises the benefits of implementation of the concepts.

This research produced a number of findings. Firstly, it illustrated the significant need for the integration of constructability, operability and maintainability concepts, specifically within multi-faceted infrastructure projects. Secondly, by categorising the key issues that cause problems for O&M professionals, an initial framework was developed. Finally, the current practices applied in different project phases by O&M stakeholders were explored, including the identification of the core principles central to the successful performance of O&M. These findings culminated in the development of an extended constructability model to improve the delivery of the project life-cycle (PLC) rather than the construction phase only.

The constructability extended model results in the delivery of projects that are not only fitted for construction purposes, but also for use. It is anticipated that the development of this model could reduce a significant number of reworks, mistakes, extra costs and time wasted during the delivery stages of multi-faceted building projects, leading to more successful delivery of infrastructure projects by integration of the three main conceptions of constructability, operability and maintainability. This model covers O&M considerations, in addition to construction concerns.

Keywords

Project Success, Integration, Constructability, Buildability, Operability, Maintainability, Fit for Purpose, Operation and Maintenance, Health Infrastructure Projects, Project Life-Cycle, Multi-faceted Building Projects, Successful Delivery, Case Study, Planning and Design

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List of Abbreviations

O&M – Operation and Maintenance

PLC – Project Life-Cycle

CII – Construction Industry Institute

CIRIA – Construction Industry Research Information Association

CIIA – Construction Industry Institute Australia

COM – Construction, Operation and Maintenance

QH – Queensland Health

CSF – Critical Success Factor

TH – Toowoomba Hospital

RBWH – Royal Brisbane and Women's Hospital

GCUH – Gold Coast University Hospital

AMSU – Asset Management Services Unit

CHRISP – Centre for Healthcare Related Infection Surveillance and Prevention

CDP – Capital Delivery Program

HIDD – Hospital Infrastructure Development and Delivery

CIMR – Capital Infrastructure Minimum Requirements

CWMF – Capital Works Management Framework

MMF – Maintenance Management Framework

SAMF – Strategic Asset Management Framework

DDMP – Design Decision Making Process

NSW – New South Wales

BCA – Building Code of Australia

TS11 – Technical Series 11

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: _QUT Verified Signature_

Date: ____2 April 2014___________

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List of Publications

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Operability and maintainability principles within health infrastructure projects. *In preparation for* Journal of Management in Engineering.

Construction, Operation and Maintenance Ability Model for health infrastructure projects. *In preparation for* Journal of Management in Engineering.

Conference Papers:

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Chapter 1: Introduction

1.1 PROBLEM STATEMENT

Infrastructure is central to communities and economic activities, providing improved public services, human development, financial enlargements and productivity. As countries grow, the demand for infrastructure projects continues to increase. The development of infrastructure projects is becoming a significant worldwide business, although it is very complex at both national and international levels (Howes & Robinson, 2005).

Construction infrastructure provides a platform for other economic sectors such as energy, trade and tourism. It is an essential contributor to growth by providing physical foundations. Moreover it can generate many jobs in developing countries. For this reason, the successful delivery of infrastructure projects has always been at the centre of attention of project owners.

Successful delivery of infrastructure projects requires the management of all the project stakeholders during the planning, design and construction, as well as operation and maintenance phases. Different studies have highlighted various success factors for infrastructure projects; however, the lack of continuous integration amongst different project stakeholders was indicated as one of the major reasons preventing project success. Therefore, ease of integration processes could significantly help to improve the successful delivery of infrastructure projects, and save a lot of time and cost.

Project success can be achieved through different integration processes; however, many researchers have suggested the integration of ideas from later project life-cycle (PLC) stakeholders into the planning and design stages as an effective method to provide successful project delivery. This is currently being implemented through the three different concepts of constructability, operability and maintainability.

The concept of constructability uses valuable and timely construction inputs into the planning and design development stages to provide significant savings in terms of the cost and time of an infrastructure project (Construction Industry Institute, 1986). The concepts of operability and maintainability also use similar strategies to ease the operation and maintenance (O&M) of infrastructure projects through early consideration of the operational and maintenance issues. In spite of the implementation of many constructability review programs in infrastructure projects, project owners still suffer from the costs of reworks and problems during the O&M phases. This research gap is that the current approach to the construction and O&M of infrastructure projects has separated the planning and design phases from other project phases. This separation has resulted in a large degree of isolation of the professionals from technical and operational developments (Wells, 1986). The Construction Industry Institute Australia (1993) also admitted that the separation of the PLC phases is one of the main reasons for projects exceeding budgets and timing deadlines. This separation has resulted in lack of an efficient and effective implementation of the three concepts for the successful implementation of infrastructure projects.

Griffin (1993) stated that 50-80% of the total PLC costs are spent during the post-occupancy phases. The current state of knowledge has given rise to some models to optimise O&M problems, resulting in projects with longer life-cycles and better efficiency (Barabadia et al., 2011; Cooke & Paulsen, 1997; de Silva et al., 2004; Keller & Al-Saadi, 1992; Kobbacy et al., 1997; Madu, 1990; Thomas, 1985; Valdes-Flores & Feldman, 1992); however, they have still failed to have comprehensive and continuing influences on the whole PLC. This highlights the need to re-examine the post-occupancy stages of infrastructure projects.

1.2 RESEARCH PURPOSES

This research aims to develop a model to improve the effectiveness and efficiency of the operability and maintainability of infrastructure projects by extending the constructability concept to include O&M phases. This research uses the concept of constructability as the foundation to address the O&M concerns, reasoning that it has been comprehensively studied, practised and developed compared with the other operability and maintainability concepts.

To achieve the aim, this research addresses the following research questions:

1) What are the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects?

2) How can the operability and maintainability be integrated with constructability for the successful implementation of infrastructure projects?

To answer the research questions, this research aims to achieve the following objectives:

1) To identify the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects.
2) To develop a model that extends the concept of constructability to include operability and maintainability considerations for the successful implementation of infrastructure projects.

This research focuses on health projects which involve multi-faceted social infrastructure. It assesses their current practices in incorporating the operational and maintenance considerations into the delivery phases of the PLC.

In business, process management looks after repeatable processes to improve overall project outcomes (Tham, 2009); however, this research aims to facilitate proper integration of project phases with the main focus on the project management area. It is all to achieve one single goal that is to improve the effectiveness and efficiency of the operability and maintainability of infrastructure projects.

1.3 THESIS OUTLINE

To achieve the research aim, Chapter 2 provides an overview of the extant literature on the successful delivery of infrastructure projects, starting with a brief explanation of different PLC phases and their importance. Then, it highlights integration as one of the prominent factors for the successful delivery of infrastructure, followed by categorisation of the current O&M problems into five groups based on the literature. Lastly, it explains how integration of the three distinct yet related concepts – namely, constructability, operability and maintainability – result in infrastructure project success.

Chapter 3 reviews the literature relevant to the concepts of constructability, operability and maintainability. Then, it discusses the reasons why the concept of constructability is considered as the platform for extension to fulfil the integration idea that was highlighted in the previous chapter. This is where the research aim is clearly identified, which is to extend the constructability principles to include the O&M phases. Finally it is concluded with the presentation of a framework to integrate constructability principles into the O&M phases.

Chapter 4 focuses on the research design and methodology. It starts with an explanation of the philosophical position of the study. It then highlights the research framework, followed by a detailed reasoning for the selection of methods, as well as the software used for analysis purposes. It also explains the correlations between the research questions, objectives, methods, data collection techniques and the data analysis method in a simple format. It also presents an overview of the details of the case study, the selection of the case study projects, and the data analysis.

Chapter 5 explores the problems that O&M professionals are facing in their everyday practices. It then categorises the current practices that are regularly implemented to address these problems.

Chapter 6 then describes the results obtained to answer the first research question, which is to identify the principles for the effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects. This chapter uses the results of Chapter 5 as the base for further development of the operability and maintainability principles. In addition to the data arising from the case analyses, the implications from existing guidelines are also used to help in the development of the operability and maintainability principles.

Based on the analysis adopted in the previous two chapters to develop the operability and maintainability principles, Chapter 7 discusses the findings, integrates the constructability principles with the newly designed operability and maintainability principles and comes up with an extended constructability model. Lastly it verifies the extended constructability model which is named the construction, operation and maintenance (COM) ability model, and discusses the implications of each principle and shows how the new model complements the available literature.

Chapter 8 is the final chapter in this thesis. It provides a summary of the findings, discusses the general conclusions of the study, and outlines the implications and recommendations for future research projects.

Chapter 2: Project Success in the Delivery of Infrastructure

2.1 INTRODUCTION

This chapter provides an overview of the current literature on the successful delivery of infrastructure projects. It highlights integration as one of the prominent factors for the successful delivery of infrastructure.

Section 2.2 discusses infrastructure projects, explains the significance of different PLC phases and highlights the definitions given for every single phase. This is followed in Section 2.3 by an account of the successful delivery of infrastructure projects. This includes a review of the literature on successful project delivery factors and introduces integration as one of the major success factors. Then, Section 2.4 discusses the current problems in the O&M of infrastructure facilities. This lays the groundwork for Section 2.5, which argues the need to integrate the different phases of the infrastructure PLC. It highlights the importance of the incorporation of different PLC phases and suggests the integration of the three concepts of constructability, operability and maintainability as a way to improve the delivery of infrastructure projects. Finally the chapter is summarised in Section 2.6.

2.2 INFRASTRUCTURE PROJECT LIFE-CYCLE

In general, the Oxford Dictionary (2009) defines infrastructure as “basic physical and organizational structures needed for the operation of a society or enterprise or reproductive system”. Infrastructure projects are the key to supporting a nation’s social and economic development. The provision of infrastructure projects involves a number of stakeholders with their own specific roles, demands and objectives. The various stakeholders of infrastructure projects will continue to demand value for money for their investment. To satisfy the conflicting demands of project stakeholders and to drive the strategic route and operational superiority of an organisation, top managers must engage the project stakeholders in order to develop infrastructure assets that are responsive to their needs (Facility Reporting Project, 2007). The engagement of different project stakeholders requires a proper understanding of the PLC phases (Aaltonen & Kujala, 2010). For this reason this section explores the PLC of infrastructure and shows the significance of each phase separately.

The PLC is defined as the number of phases that provide a fundamental structure for an appropriate project management process (ASCE, 1990). The life-cycle of a project includes a collection of sequential phases that provides the basic framework for project management purposes (Infrastructure Ontario, 2010). The Project Management Institute (2008) stated that an accurately planned project consists of four phases: (1) project conception and initiation, (2) project definition and planning, (3) project launch and execution, (4) project performance and control, and (5) project close. Kartam (1997) classified the PLC into four phases, namely, concept, design, construction and operation. Banaitiene et al. (2008) also divided the PLC into four stages of plot, building, maintenance and demolition.

Some authors and standards have provided more detailed categorisations for the PLC phases. For example, in the costing of infrastructure projects, Wubbenhorst (1986) used the five phases of initiation, planning, realisation, operation and disposal/salvage. The infrastructure Ontario Centre (2010) classified the PLC into the business case, planning, design, procurement, construction, commissioning and handover/operational readiness, and lastly, the close-out phases. Howes and Robinson (2005) also classified the PLC phases into five groups of planning, design, construction, operation and recycling/disposal, which they defined separately as follows:

(1) The planning phase involves the definition of the project purposes, selection of a suitable work site, and the endorsement of the outline planning and feasibility studies.

(2) The design phase consists of the schematic and detailed design stages to fulfil the needs of the contractors and clients.

(3) The construction phase covers all the activities, equipment, materials, on-site elements and labour, based on complete realisation of the clients’ interests.

(4) The post-occupancy phase includes the O&M of the infrastructure assets ending with recycling/disposal of the project.

Barrie and Paulson (1992) divided the PLC into seven phases, namely:

(1) Concept and feasibility studies;

(2) Engineering and design;

(3) Procurement;

(4) Construction;

(5) Start-up and implementation;

(6) Operation and utilisation; and

(7) Demolition and conversion.

In spite of the different models given for the classification of the PLC phases, all of them are similar in having classifications that include the planning, development, construction, and post-occupancy phases. These in-common phases are also defined by Russell (n.d.) as, firstly, the planning phase that includes the preliminary feasibility studies on the project. Secondly, the development phase includes both the conceptual and detailed design steps. Thirdly, the construction phase consists of all the activities, equipment and on-site labour, and finally there is the post-occupancy phase that includes the O&M of the delivered project. These four phases are clearly associated with the aim of the current study, that is, to take the post-occupancy concerns into account in the early decision-making processes within the planning, development and construction phases. This research focuses on the pre-disposal stages of infrastructure projects, because the nature of the activities in the disposal phase is very different from other project phases, and as a result, it is not relevant to consider the recycling and disposal stages as a separate phase in the classification of PLC phases for this specific research project.

The successful implementation and delivery of infrastructure projects has always been a critical issue for infrastructure project owners. The proper incorporation of project stakeholders' concerns from different PLC phases has a significant influence on the achievement of all the project objectives. For this reason, the next section identifies the different factors for successful delivery of infrastructure projects and lays the ground work to define the study scope.

2.3 SUCCESSFUL DELIVERY OF INFRASTRUCTURE PROJECTS

Since the late 1960s, researchers have been trying to identify the factors that lead to project success in infrastructure (Cooke-Davies, 2002). A project management process is successfully delivered if it is completed on time and within budget, while at the same time it satisfies the expectations of the different project stakeholders (Lim & Mohamed, 1999; Nguyen et al., 2004). On the other hand, De Wit (1998) stated that the project success is fully achieved when there is a high level of satisfaction among the key people in the parent organisation, the key people in the project team and the key people among the clients/users of the project.

The subject of success factors in infrastructure projects has attracted many researchers from different disciplines aiming to achieve valuable findings for the projects; however, its definition is sometimes mistaken with the concept of project management success. The project success factors are “any knowledge, skill, trait, motive, attitude, value or other personal characteristics that is essential to perform the job or role that differentiates solid from superior performance” (PEPDS, 2004). Rockart (1979) defined project success factors as the key areas of activity in which great findings are necessarily needed for a manager to reach his/her objectives. Sanvido et al. (1992) also defined project success as the extent to which the project’s aims and expectations are met. Project management success has a different meaning. For example, Ashley and Jaselskis (1987) defined project management success as “results much better than expected or normally observed in terms of cost, schedule, quality, safety and participant satisfaction”. Boynton and Zmud (1984) also defined project management success factors as those things that must go well to cause success for the project management team or organisation. Despite some contention in the understanding of these two concepts, this research looks at the broad definition of success for infrastructure projects to include considerations of the post-occupancy stakeholders.

The concepts of “fit for purpose”, functionality and profitability have been considered as a unit of measure for project success (Takim & Akintoye, 2002). Belassi (1996) explained that project success is usually measured based on both product and project management success. Baccarini (1999) echoed a similar statement, saying that the success of the facilities and project management team may also be considered as a unit of measure for project success. For those involved in the projects, project success is the achievement of some pre-defined goals, while users have another perception of the outputs of the project (Lim & Mohamed, 1999). Lim and Mohamed (1999) concluded that project users or clients usually have a macro viewpoint of the project success, while construction parties are mostly concerned with micro viewpoints, meaning that the users/clients check if the original concept is ticked, while construction people concentrate on checking the criteria. It should also be noted that success in large-scale projects depends on different aspects, including human-related, project management-related, and external environment-related factors (Salleh, 2009).

There are many factors out of the management team's control that negatively affect the project objectives (Belassi & Tukel, 1996). Moreover, there is always ambiguity in determining whether a project has been successfully implemented or not, because different project stakeholders will have different definitions and perceptions of a project's success (Belassi & Tukel, 1996). Project success can only be measured until after the project is completed (Cooke-Davies, 2002). Because of these diverse perceptions of the definition of project success, lists of success factors in various studies are significantly different from each other. In addition, some research has shown that most success factors cannot individually result in infrastructure project success; rather, it is only their combination that can positively lead to success. Thus having a clear understanding of the nature of existing success factors helps to the further research into the success factors for infrastructure projects.

There is much research showing different categories for success factors. Each study has its own method of categorisation. Some have introduced factors that are more crucial to the project success than the others. These factors are called the critical success factors (CSF) of infrastructure projects. Rockart (1982) first used the term CSF and defined it as "the factors predicting success on projects". Studies on the identification of success factors are very different in scope. Some considered that success factors were the factors for successful project delivery as a whole; others explored success factors for building projects only; many others discovered success factors for different project objectives or over the PLC stages; and some researchers explored the CSFs.

The successful delivery of infrastructure projects is a crucial matter; that is why much research has aimed to develop conceptual frameworks for project CSF. Westerveld (2003) categorised the CSF that were identified by four studies based on a list of result areas. Fortune and White (2006) also did a comprehensive review of 63 publications and summarised the CSF into 27 categories. Ika et al. (2012)

summarised research on CSF for international development projects. Among such diverse studies on CSF, the study implemented by Chan (2004) remains prominent as a work widely referenced by other authors. Chan (2004) developed five major variables as crucial to project success. Salleh (2009) also carried out inclusive research aiming to categorise the success factors of infrastructure projects few years ago which covered most of the collected literature on success factors. For the purpose of the present study, the work of Chan (2004) and Salleh (2009) is summarised in Table 1 as a comprehensive list of success factors.

Table 1. Success factors in infrastructure projects
(Adopted from Chan, et al., 2004; Salleh, 2009)

Success Factors	**Variables**
Project-related factors affecting project success	• Type of project • Nature of project • Definition of project • Project mission • Number of floors of the project • Size of project • Complexity of project (Akinsola et al., 1997; Belout, 1998; Cooper & Kleinschmidt, 2003; Dissanayaka & Kumaraswamy, 1999a, 1999b; Pinto & Slevin, 1987; Songer & Molenaar, 1997; Walker, 1995)
Procurement-related factors affecting project success	• Proper procurement method • Suitable tendering method • Contractual motivation and incentives (Akinsola, et al., 1997; Dissanayaka & Kumaraswamy, 1999b; Salleh, 2009; Walker, 1995; Walker & Vines, 2000)
Project management-related factors affecting project success	• Top project management support • Communication system • Control mechanism • Trouble-shooting • Feedback capabilities • Planning effort • Developing an appropriate organisational structure • Implementing an effective safety program • Control of sub-contractors' work • Overall managerial actions • Competent project manager

(Cont'd)

Success Factors	Variables
	(Ashley & Jaselskis, 1987; Belout, 1998; Chua et al., 1999; Hubbard, 1990; Jaselskis & Ashley, 1991; Pinto & Slevin, 1987; Salleh, 2009; Walker & Vines, 2000)
Project participant-related factors affecting project success (client, contractors, sub-contractor, suppliers, manufacturers)	• Client's experience and skills • Nature of client • Size of client organisation • Client emphasis on low construction cost • Client emphasis on high quality construction • Client emphasis on quick construction • Client acceptance • Client ability to approve • Client ability to make decisions • Client ability to define roles • Client's contribution to design • Client's contribution to construction • Project team leaders experience • Competent project team • Project team commitment • Technical skills of project team leaders • Planning skills of project team leaders • Organising skills of project team leaders • Coordinating skills of project team leaders • Motivating skills of project team leaders • Project team leaders' commitment to meet cost, time and quality • Project team leaders' early and continued involvement in the project • Project team leaders' working relationship with others • Support and provision of resources • Site inspections (Belassi & Tukel, 1996; Chan & Kumaraswamy, 2002; Chua, et al., 1999; Cooper & Kleinschmidt, 2003; Hassan, 1995; Pinto & Slevin, 1987; Salleh, 2009; Songer & Molenaar, 1997; Walker, 1995)
External-related factors affecting project success	• Economic environment • Social environment • Political environment • Physical environment • Industrial relations environment • Technologically advanced • Health and safety (Akinsola, et al., 1997; Ashley & Jaselskis, 1987; Chua, et al., 1999; Cooper & Kleinschmidt, 2003; Kamming et

(Cont'd)

Success Factors	Variables
	al., 1997; Salleh, 2009; Songer & Molenaar, 1997; Walker & Vines, 2000)

Salleh (2009) stated that to achieve comfort, competence, commitment and communication in infrastructure projects, there is a significant need to integrate all the parties associated with the project into the management, planning, design, construction and operation stages of the PLC. Sanvido et al. (1992) confirmed that the lack of integration among different project parties prevents infrastructure projects from achieving success by separating the PLC phases. It results in project stakeholders who are not aware of the concerns in other phases. The concept of integration provides a platform for further achievement of the project success. The above highlighted success factors, especially the project management-related and project participant-related factors, also show the significance of the integration of ideas from different project stakeholders along the PLC phases. For instance, success factors such as early consideration of clients' experience and skills, feedback capability, implementing safety programs, proper communication skills, and early project leaders' involvement, are good examples to show the significance of the integration concept helping to enhance the successful delivery of infrastructure projects. Salleh (2009) also revealed that project success can be enhanced if project characteristics are well understood by the managerial team through the accurate control of project steps under appropriate contractual arrangements. This happens when the client/user needs are properly analysed in the early project phases and their concerns are well integrated into the planning or design sketches.

Infrastructure project programming is a complex and iterative process to identify the real needs of the clients/users. It is a technique to identify whether the project success is achieved or not (Yu et al., 2006). There are various major problems in the achievement of project success, including inexperienced clients, lack of proper identification of client's needs, lack of sufficient integration of the clients in briefing, inadequate briefings, late briefings and contractors being unfamiliar with client objectives (Barrett & Stanley, 1999; Kamara & Anumba, 2001; Kelly et al., 1992; Yu et al., 2005). Heising (2012) stated that a proactive management of the whole project is increasingly important to achieving long-term success. He argued that opportunities are discovered at the front end of a project, so having an understanding of how different phases should integrate with each other can make a major improvement in project management process. Lack of integration of users' expectations in the early phases is the nature of many of these problems, and research focusing on the ease of the integration process can significantly improve the likely achievement of project success.

Before designing a framework to enhance the integration process in infrastructure projects, there is a need to identify the challenges confronting the close relationship of project planners, designers, contractors, O&M stakeholders, and clients/users. The next section highlights a summary of O&M problems that mostly occur because of a lack of proper integration by pre- and post-occupancy personnel.

2.4 PROBLEMS IN O&M OF INFRASTRUCTURE PROJECTS

The costs of failures in the O&M phases of multi-faceted infrastructure projects are significant, compared with other project types. This is because of the high costs of the O&M phases and the lack of a comprehensive study which integrates the whole PLC in a unique framework (Al-Hammad et al., 1997; Assaf et al., 1996; Dunston & Williamson, 1999; Geile, 1996; Griffin, 1993; Ivory et al., 2001; Lam, 2007; Russell, n.d.). The literature on the existing problems in the O&M of infrastructure projects indicates five categories of problems: (1) technical, (2) managerial, (3) political or legal, (4) environmental, and (5) social or cultural.

Technical Problems

Technical problems have always been significant sources of costly reworks during the O&M phases of infrastructure projects. They do not belong to a specific phase and may occur during the planning, design, construction or even post-construction phases of infrastructure projects. They include:

- Building characteristics and design problems

Technical problems can be avoided as early as the planning and design phases through an early decision-making process on building characteristics (Al-Zubaidi, 1997; Arditi & Nawakorawit, 1999; Azlan Shah et al., 2010; Christer & Whitelaw, 1983; El-Haram & Horner, 2002; Josephson & Hammarlund, 1999; Kalamees, 2002; Lam, 2007; Lam et al., 2010; Lateef, 2009; Lavy & Shohet, 2009; Shen, 1997;

Shohet, 2003; Shohet et al., 2002, 2010; Souponitski et al., 2001; Uhlik & Hinze, 1998; Williams & Clark, 1989) or design problems (Al-Hammad, et al., 1997; Allen, 1993; Arditi & Nawakorawit, 1999; Assaf, et al., 1996; Christer & Whitelaw, 1983; Duling et al., 2006; Flores-Colen & Brito, 2010; Josephson & Hammarlund, 1999; Kalamees, 2002; Lam, 2007; Lam et al., 2007; Lateef, 2009; Souponitski, et al., 2001; Williams & Clark, 1989). Both areas highlight the need for the integration of O&M knowledge and skills into the earlier project phases in addition to construction concerns. This would prevent misunderstandings about the project characteristics, as well as the ambiguities of designers toward the O&M concerns.

- Construction-related issues

Construction-related issues are those problems which occur during O&M phases because of faulty or untested constructions, or as a result of inefficiencies of construction stakeholders. Low quality construction is one of the major technical problems and results in the need to carry out many repairs during the O&M phases. Urgent action is needed in order to resolve or reduce these problems (Al-Hammad, et al., 1997; Assaf, et al., 1996; Flores-Colen & Brito, 2010; Shen, 1997; Souponitski, et al., 2001). The knowledge and methodologies applied during the planning and design stages must be O&M-oriented in order to prevent such problems, which mostly arise because of the separation of the construction phase from the O&M phases.

- Maintenance-related issues

Maintenance related issues are those failures occurring because of faulty maintenance procedures, interpersonal conflicts, wrong maintenance policies, improper locationing, and having staff with poor knowledge. Maintenance-related issues might be among the most critical technical problems having diverse and direct influences on successful project delivery, while their consideration during the early planning and design stages must be an integral part of the project plan. (Al-Zubaidi, 1997; Al-Zubaidi & Christer, 1997; Allen, 1993; Assaf, et al., 1996; Azlan Shah, et al., 2010; Christer & Whitelaw, 1983; Duffuaa et al., 2001; El-Haram & Horner, 2002; Flores-Colen & Brito, 2010; Josephson & Hammarlund, 1999; Lai & Yik, 2007; Lam, 2007; Lateef, 2009; Lavy & Shohet, 2009; Paz & Leigh, 1993; Shen, 1997; Shohet, 2003; Shohet, et al., 2010; Souponitski, et al., 2001). Getting to know the corporate objectives of the clients leads to better maintenance implementation. In order to achieve that, bringing the skills and knowledge of O&M personnel to the early stages of planning or conceptual design can have a significant influence on decreasing the number of O&M problems or reworks.

- Fast technological advances and high occupancy level issues

Fast technological advances in the construction industry and the high occupancy level of buildings are two important issues which affect O&M phases significantly. They are the causes of many problems for O&M personnel, because infrastructure projects are not usually flexible enough to adapt to new technological situations with such a large number of clients (Lam, et al., 2010; Lavy & Shohet, 2004; Pintelon & Gelders, 1992; Shen, 1997; Shohet, 2003; Shohet, et al., 2002; Williams & Clark, 1989). Having a realistic and O&M-sensitive program for the entire infrastructure project can considerably reduce the amount of reworks resulting from such major problems. As another approach, using innovative O&M ideas at an earlier time during the PLC can prevent the problems caused by fast technological advances and high occupancy levels and facilitate the successful achievement of the overall project objectives.

Managerial Problems

Managerial problems have always been the cause of many operational and maintenance problems or reworks in infrastructure projects. These problems are grouped into three main categories, as follows:

- Project management issues

Project management issues are among the most critical sources of problems during the post-occupancy phase (Al-Hammad, et al., 1997; Al-Zubaidi, 1997; Duffuaa, et al., 2001; El-Haram & Horner, 2002; Josephson & Hammarlund, 1999; Lam, et al., 2007; Shen, 1997; Uhlik & Hinze, 1998). Some of these problems are related to the lack of an efficient and effective stakeholder management process and incomplete construction phase documentations. Some others, like organisational constraints, lack of time, poor relationships or unclear decision-making processes, are related to the inefficient managerial structure of companies. Resolving project management problems requires early consideration of the ideas of O&M personnel. They can be grouped as external factors which can significantly affect project plans, and must be considered in the final target model.

- Economic and financial issues

A limited budget is an eternal problem for the whole infrastructure project sector. It has always caused many problems for O&M staff, and becomes extreme when project planners underestimate the O&M costs (Arditi & Nawakorawit, 1999; Azlan Shah, et al., 2010; Christer & Whitelaw, 1983; Duffuaa, et al., 2001; El-Haram & Horner, 2002; Flores-Colen & Brito, 2010; Josephson & Hammarlund, 1999; Lam, 2007; Lam, et al., 2010; Lateef, 2009; Lavy & Shohet, 2004, 2009; Pintelon & Gelders, 1992; Uhlik & Hinze, 1998; Williams & Clark, 1989). This highlights that it is so important for programming to be O&M-sensitive, in addition to being construction responsive. Efficiency in developing project specifications might also enhance the financial aspects of O&M implementation.

- Resource management issues

There are many problems reported that are related to the inadequate management of resources in O&M phases. They can be grouped into the two major categories of limitation of equipment and selection of low quality materials (Al-Zubaidi, 1997; Al-Zubaidi & Christer, 1997; Allen, 1993; Assaf, et al., 1996; Azlan Shah, et al., 2010; Duffuaa, et al., 2001; Duling, et al., 2006; El-Haram & Horner, 2002; Flores-Colen & Brito, 2010; Josephson & Hammarlund, 1999; Lai & Yik, 2007; Lam, 2007; Lam, et al., 2010; Lateef, 2009; Lavy & Shohet, 2004; Shen, 1997; Shohet, 2003; Shohet, et al., 2002, 2010). Detailed planning and design are needed to analyse the available human resources, equipment and services for a more efficient O&M implementation. This helps to deliver a more beneficial management of resources based on the needs of the clients.

Political and Legal Problems

Political and legal problems consist of governmental restrictions and contracting defects. Political and governmental restrictions have always limited O&M activities through onerous or inconsistent legislation. (Al-Zubaidi, 1997; Assaf, et al., 1996; Azlan Shah, et al., 2010; Flores-Colen & Brito, 2010; Josephson & Hammarlund, 1999; Lam, 2007; Lateef, 2009; Lavy & Shohet, 2009; Shen, 1997; Uhlik & Hinze, 1998). Missing contracting requirements and changing regulations also result in many problems for O&M personnel (Ivory, et al., 2001; Shen, 1997). They cause similar problems for the O&M of infrastructure projects, resulting in an ineffective facilities management process. Both political and legal factors seem to be among the external factors which are often overlooked during the planning and initial programming of infrastructure projects. The early programming for political, legal and governmental restrictions might be a potential solution for this problem.

Environmental Problems

Environmental issues cause different problems for the O&M of infrastructure projects, such as degradation problems, environmental changes, and the limitation of using environmentally friendly materials (Al-Hammad, et al., 1997; Allen, 1993; Assaf, et al., 1996; Duling, et al., 2006; Flores-Colen & Brito, 2010; Josephson & Hammarlund, 1999; Kalamees, 2002; Lam, et al., 2010). The integration of O&M staff with planners and designers, and integration of their skills and knowledge with other project stakeholders, can make significant contributions to the environmental and biological situation of projects. Environmental issues are also among the external factors considered in the final target model in the present research. In addition, a wider programming is needed in order to include environmental considerations as early as possible. A review of feedback from O&M staff about the environmental and biological issues of the project might also be a good way to resolve the negative influences of these factors on the achievement of total project objectives, as well as facilitating an easier and smoother successful project delivery.

Social and Cultural Problems

The safety and security of project end-users have been among the critical issues for O&M staff for many years. These problems are absolutely the root of many other social and cultural defects which are repeatedly highlighted in different studies (Al-Zubaidi, 1997; Allen, 1993; Arditi & Nawakorawit, 1999; Azlan Shah, et al., 2010; Christer & Whitelaw, 1983; Lam, 2007; Lam, et al., 2010; Lavy & Shohet, 2004; Pintelon & Gelders, 1992; Shen, 1997; Shohet, et al., 2002, 2010). User expectations of a well-organized operation process make the job harder for O&M personnel, specially the expectations of female users (Al-Momani et al., 2006; Al-Zubaidi, 1997; Allen, 1993; Arditi & Nawakorawit, 1999; Assaf, et al., 1996; Azlan Shah, et al., 2010; El-Haram & Horner, 2002; Flores-Colen & Brito, 2010; Griffin, 1993;

Josephson & Hammarlund, 1999; Lai & Yik, 2007; Lam, et al., 2010; Lateef, 2009; Lavy & Shohet, 2009; Paz & Leigh, 1993; Shen, 1997; Shohet, et al., 2002, 2010; Uhlik & Hinze, 1998; Williams & Clark, 1989). Having safety and security review sessions at the initial stages of the PLC can be an effective method for better project planning. Consideration of the users' corporate objectives and the project aims at the same time is another important method which can significantly help to prevent social and cultural defects.

These categories of problems need to be systematically examined and evaluated during the planning and design phases to ensure the successful delivery of infrastructure projects. In fact, many of these problems arise because of the lack of attention to O&M concerns during the planning, design, and construction phases, justifying the need for incorporation of O&M considerations into earlier infrastructure project phases. The next section focuses on the need to integrate various phases of the infrastructure PLC. It aims to identify the ways proposed in the literature to enhance the integration mechanism to improve the successful delivery of infrastructure projects.

2.5 INTEGRATING VARIOUS PHASES OF THE PROJECT LIFE-CYCLE

As stated above (Section 2.3), project success is the main goal of infrastructure project owners, and integration of project concerns into different PLC phases could significantly help achieve a smoother and more successful delivery of projects; however, some studies have shown that the integration of project concerns into the PLC is underexposed and underestimated (Heising, 2012; Khurana & Rosenthal, 1997, 1998). The different O&M problems that are caused by improper integration of O&M concerns with earlier project phases have been highlighted above. This section explores the integration concept in detail and highlights the goal of the present research which is to improve the delivery of infrastructure projects through a more comprehensive integration process.

The term 'integration' is generally defined as "the act or process of making something whole and entire'' ("Webster's revised unambridged dictionary," 1913). In the project management field, it is defined as "the sharing of information between project participants or melding of information sourced from separate systems" (O'Connor & Yan, 2004). Kirsla et al. (2007) defined it as "bringing or joining together a number of distinct things so that they move, operate and function as a harmonious, optimal unit". According to the PMI (1996), integration is a process to make sure different project elements are properly coordinated. The concept of integration is becoming more relevant and complicated these days due to the various combinations of users' needs (Kirsila, et al., 2007). In construction, integration refers to all collaborative, practices, techniques and attitudes that allow information to be freely exchanged among different stakeholders (Baiden & Price, 2011). Integration is indeed at the heart of much research in the field of construction management, because of such complexities. Kirsila et al. (2007) concluded that the concept of integration should be used as a means for successful delivery and transformations.

Heising (2012) highlighted personnel, technocratic and financial integrations as positively related to project success. The proper management of project stakeholders, including early identification and on-time integration, leads to increased project front-end success. Integration technologies can significantly enhance the management of project stakeholders (Yan et al., 2006), leading to projects with a higher level of stakeholder involvement in early PLC phases. Some researchers and practitioners have raised the importance of early involvement of project users' needs as an important success factor in infrastructures (Cooper et al., 2004; Hsu et al., 2011; Markus & Mao, 2004; Thomke & Vvon Hippel, 2002). This was also supported by Hsu et al. (2011) who stated that the integration of users and developers resulted in communal minds and verified that project success is more productively reached as user and developer integration improves. The integration of users and developers is necessary to merge their efforts to maximise the performance (Tesch et al., 2009). In addition, Voss (2012) believed that the value of different project stakeholders can be increased due to the right integration processes.

In addition to the involvement of stakeholders in the planning and design stages, there is some other evidence showing how the concept of integration can lead to project success. Dodin and Elimam (2008) stated that the sequencing of equipment in the project planning stage results in various trade-offs in expenses. It generates practical schedules at the lowest costs. In brief, equipment planning and project scheduling are inseparable. Ying et al. (2006) added the integration of resource management knowledge to the list, stating that such integration provides support for a more consistent organisational configuration. According to Tiwana et al. (2003), informal integration which occurs through unstructured communication "may help in building bridges and exchanging ideas" and formal integration through coordinators and managers "may ensure more systematically distributing knowledge". Martinsuo and Ahola (2010) highlighted the sample of the noble integration model, which was the integration of project suppliers and contractors resulting in smoother delivery of complex projects. In addition to these models for the concept of integration, studies on the concept of "fit for purpose" have also made some contributions to this area. Cox and Thompson (1997) designed a model for enhancing contractual relations aiming to fit the project objectives to the real needs of the users.

Boland and Tenkasi (1995) explained that integration:

> "is not meant as an act of smoothing over differences and arriving at one single, unified understanding. Rather, it is a way of sharing unique understandings that can result in expansion of a meaning structure's frame of reference… A process of surfacing and examining interpretations allows a shaking of the background of consensus and opens the possibility of mutual interpretation that enables the achievement of a new definition of the situation in which all participants can share".

The models and approaches presented in the literature show the high level of awareness among practitioners regarding the considerable consequences of the integration of ideas from different PLC phases to achieve more successful project delivery. Project success can be achieved through each of the above integration processes. However, in accordance with a comprehensive study by Trigunarsyah and Skitmore (2010), to achieve a realistic and inclusive successful delivery it is important to integrate ideas from different project phases for three reasons: firstly, to achieve the overall aims of the project; secondly, to fit the final project for its intended use; and thirdly, to maintain project facilities efficiently in order to postpone their recycling and disposal. The constructability concept enriches the first one through the involvement of construction experience and knowledge into the pre-occupancy phases; the operability concept enriches fitting the project for its intended use through bringing O&M stakeholders into early project phases; and, finally, the maintainability concept concerns the involvement of maintenance stakeholders in the early project phases. These three concepts are introduced as three comprehensive techniques to facilitate the integration process for faster and easier achievement of project success. It is necessary to have a better understanding of these three concepts and check the current possibilities for improvement. For this reason, next chapter reviews these concepts in more detail.

The need to integrate the constructability, operability and maintainability concepts

The current approaches to construction and O&M have separated the decisions made within the planning and design phases from the construction and post-construction decisions. This separation has resulted in a large degree of isolation of the professionals from technical and operational developments (Wells, 1986). The Construction Industry Institute, Australia (1993) acknowledged that such isolation of project phases is one of the main reasons for projects exceeding their budget and timing deadlines.

Tatum et al. (1986) believed such separation of PLC phases ignored many opportunities for major savings in project cost and time in the US construction industry. The Business Roundtable (1982) also indicated that having such an integration of ideas from different project phases has shown huge savings and is required for delivering the projects properly. The study by Wells (1986) shows how the separation among various project phases had isolated different professionals from technicians and developers. Separation means isolation of planners and designers from COM knowledge. This can easily prevent innovations and proper implementation of COM activities, and as a result, prevents the achievement of an optimum point for successful project delivery. That is why integration has been offered as a means of improving the success of cooperation and project delivery team performance (Egan, 2002; Payne et al., 2003). Integration leads to competiveness in the long-term, because the abilities to make savings and get value for money will be increased (Alshawi & Faraj, 2002; Crane, 2002; Lennard et al., 2002).

In brief, the concepts of constructability, operability and maintainability are effective integration platforms for project owners to prevent problems during the delivery of infrastructure projects; however, they have been implemented separately from each other, causing a lack of successful delivery of infrastructures. It shows that there is a significant need to integrate the three concepts in order to achieve successful infrastructure project delivery. To achieve that, this research uses the concept of constructability as the basis to address the O&M concerns, reasoning that it has been comprehensively studied, practised and developed compared with the operability and maintainability concepts. The next chapter will provide a framework to enhance the integration of these three concepts, using the concept of constructability as the basis for extension.

2.6 SUMMARY

This chapter presented the current literature on project success in the delivery of infrastructure projects. It explored the studies on infrastructure PLC, and presented a review of research on the success factors of the infrastructure projects. Then it highlighted different problems in the O&M of infrastructure projects and introduced the concept of integration as a key for improvement of the project success. Lastly, it presented the separation of the concepts as the main research gap and suggested a further review of studies on the integration of these concepts for the next chapter, aiming to improve the successful delivery of infrastructure projects.

It is very important to have a smooth integration among the different PLC phases of infrastructure projects, as the construction industry provides the base for other economic sectors. More effective and efficient integration of PLC phases will result in softer project start-up, handover and delivery, which would lead to greater contribution to project success.

The current approaches in infrastructure project management have led to the separation of ideas in different PLC phases. As highlighted by several studies, this has led to lack of integration among different project stakeholders, which has been suggested as a reason for projects failing to achieve a successful end. On the other hand, the proper interaction of different project stakeholders could lead to a more successful delivery of infrastructures, resulting in significant savings during the life of the project.

For infrastructure projects, it is very important that project stakeholders have a clear understanding of what the other stakeholders want or need. The next chapter focuses on the concepts of constructability, operability and maintainability as platforms to providing such integration among the different project stakeholders.

Chapter 3: A Framework to Integrate Constructability to Include Operation and Maintenance

3.1 INTRODUCTION

The discussion in the previous chapter showed that the successful delivery of infrastructure projects needs early consideration of different ideas from all the PLC phases. Many success factors have been suggested for infrastructure projects, in which the concept of integration plays an important role among them. Different project stakeholders are not usually well-integrated into the early project phases. Such lack of integration has led to a definite amount of segregation of professionals from technical developments and improper maintenance implementation. The concepts of constructability, operability and maintainability are implemented separately from each other and their integration can create opportunities for many savings in cost and time.

This chapter provides an overview of the current literature on the concepts of constructability, operability and maintainability. It discusses why the concept of constructability should be the basis for integrating those three concepts, and proposes a framework of the integration.

Section 3.2 explores the concept of constructability, its principles and implementation both in international and Australian contexts. Similarly, Section 3.3 sketches the same structure for the concepts of operability and maintainability. It is then followed by an explanation of the reasons for extension of the constructability concept to include the O&M phases. This includes a review of the current models/principles used for the three concepts and an evaluation of their capabilities to be considered as a platform for further development. Section 3.4 suggests a framework to integrate the constructability principles with O&M phases aiming to develop an extended version of the constructability model. Finally, the chapter is summarised in Section 3.5.

3.2 CONCEPT OF CONSTRUCTABILITY

The concept of constructability was primarily introduced in the US in the 1970s. It was introduced as a technique that connects the initial planning and design phases to the construction processes. Research on the concept of constructability in the US was a part of the Construction Industry Institute (CII) research program. The CII produced several studies on constructability. These studies were mostly around the management systems and the involvement of owners and contractors. In 1979, the Construction Industry Research Information Association (CIRIA) proposed research to explore the constructability/buildability problems in the UK construction industry. This research found that the buildability problems occurred because of the isolation of planners and designers from the construction processes, not as the result of staff shortcomings (CIRIA, 1983). Some researchers in Australia also started to select constructability as the subject of their studies in the 1980s (CIIA, 1996a). The Construction Industry Institute of Australia (CIIA) also used a similar approach to the CII in developing the concept of constructability within the Australian construction industry.

Constructability (or buildability) is a term used in infrastructure projects in many countries around the world. Various similar definitions have been provided in the literature (e.g. See Adams, 1989; CIIA, 1993; Construction Industry Institute, 1986, 1993; Ferguson, 1989; Hugo et al., 1990; Nima et al., 2001; O'Connor & Davis, 1988; O'Connor & Tucker, 1986; Russell & Gugel, 1993; Skibniewski et al., 1997; Tatum et al., 1986). The Construction Industry Institute (1986), the pioneer of this concept, defined it as “the optimum use of construction knowledge and experience in the conceptual planning, detailed engineering, procurement and field operations phases to achieve the overall project objectives”.

Previous studies have shown that improved constructability can lead to savings in both cost and time, as well as significant improvements in quality and safety, which are keys for the successful delivery of the projects (Construction Industry Institute, 1986; Construction Industry Review Committee, 2001; Francis et al., 1999; Geile, 1996; Griffith & Sidwell, 1997; Jergeas & Van der Put, 2001; Low, 2001; Oey, 2001; Paulson, 1976; Tatum, et al., 1986; Trigunarsyah, 2004b; Ugwu et al., 2004). The concept of constructability integrates construction knowledge, experience, and skills into the early planning and design phases targetting a more constructable project, which improves the efficiency of actions and leads to fewer problems during field works (Fischer & Tatum, 1997; Trigunarsyah, 2004a) and better teamwork throughout the project (Radtke & Russell, 1993). Such integration provides a clearer view of construction phase for project planners and designers. This is more critical in infrastructure projects because there are more complexities in the construction of infrastructure projects compared with smaller constructions, and these complexities often remain hidden even for the most professional planning and design teams. This can put the project in danger in terms of being on-time and within budget for successful delivery.

To achieve the optimum benefits, it is essential to consider constructability at an early stage of the PLC because the ability to influence the project cost diminishes as the project progresses in time (Griffith & Sidwell, 1995). A construction-directed design is more likely to consider the concerns of all stakeholders. It can influence the overall cost of projects much more than late action (see Figure 1). The Business Roundtable (1982) stated that the advantages obtained from a good constructability are about 10 to 20 times of the costs spent for it.

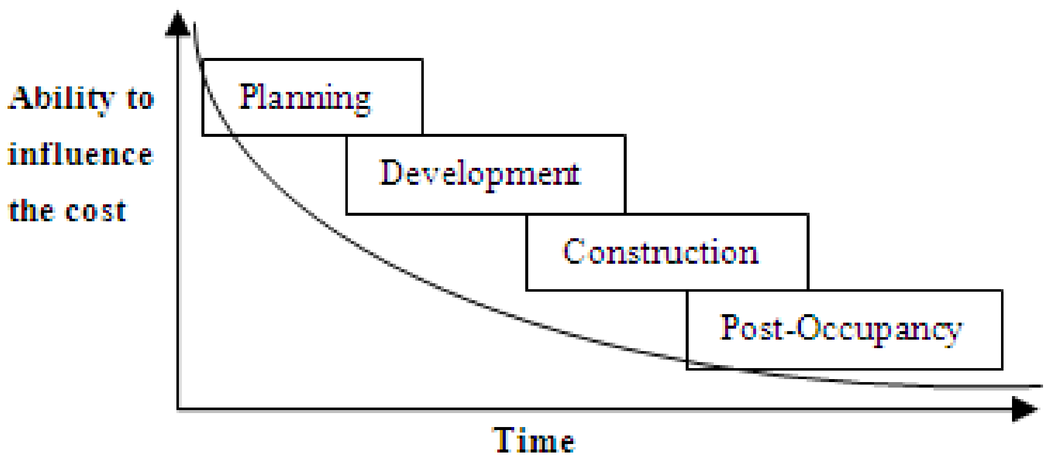


Figure 1. Cost influence curve
(adapted from Griffith & Sidwell, 1997)

Past research shows that construction knowledge and experiences have been adopted during the design and planning phases (Construction Industry Institute, 1986). Research also has shown that there was quite high awareness amongst contractors toward the implementation of constructability review programs in projects (Building and Construction Authority, 2005; Construction Industry Review Committee, 2001; Glavinich, 1995; Gray & Hughes, 2001; Nima et al., 2002; Saghatforoush et al., 2009a, 2009b; Uhlik & Lores, 1998). Awareness of post-construction issues was, however, limited. The literature suggests that although constructability review programs have many benefits for the infrastructure projects, their focus is limited to the integration of construction ideas into the planning and design only, hence limiting the impact on delivering successful projects.

Definitions and Principles

As highlighted in the previous chapter, the CII (1986) defined constructability as "the optimum use of construction knowledge and experience in the conceptual planning, detailed engineering, procurement and field operations phases to achieve the overall project objectives", and described it as a powerful tool that integrates different project functions. A timely integration of construction inputs into the early PLC phases is the only way of achieving the highest benefits from implementation of constructability. The CIRIA (1983) defined buildability as "the extent to which the design of a building facilitates ease of construction, subject to overall requirements for the completed building". The Construction Management Committee of ASCE Construction Devision (1991) defined constructability as "the application of a disciplined, systematic optimisation of the construction-related aspects of a project during the planning, design, procurement, construction, test and start-up phases by knowledgeable, experienced construction personnel who are part of a project team". The CIIA defined it as "the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goals and building performance at an optimum level". All these definitions confirm that to get the maximum benefits of constructability, early consideration of the construction concerns is a must. This is because, once the construction is started, it will be very expensive to make changes.

Constructability principles have been identified and applied in infrastructure projects over the past years, and many researchers have agreed that project stakeholders are aware of the importance of implementing constructability principles in different PLC phases (e.g. see Building and Construction Authority, 2005; Construction Industry Review Committee, 2001; Glavinich, 1995; Gray & Hughes, 2001; Nima, et al., 2002; Saghatforoush, 2009; Trigunarsyah, 2004a; Uhlik & Lores, 1998). Constructability principles have been reviewed by some organisations and many researchers for over two decades (Adams, 1989; CIIA, 1996b; CIRIA, 1983; Construction Industry Institute, 1986; Nima, 2001; O'Connor & Tucker, 1986; Tatum, et al., 1986; Trigunarsyah, 2004a). Research work done on buildability in the UK introduced seven buildability guidelines (CIRIA, 1983), including carrying out investigation and design, planning for site production needs, planning for realistic chain of operations, planning for simplicity of combinations, detailing for higher level of standardisation, detailing for attainable tolerances, and selecting safe and suitable materials. The CIRIA further developed these seven buildability guidelines into 16 design principles for the UK construction industry (Adams, 1989). Different design aspects are attended in these 16 principles such as comprehensiveness, accessibility, storage, time, fast enclosure, materials, skills, assembly, standardisation, use of plants, tolerances, chain of operations, communication, safety, probable damages, and prevention of return visits by trades.

In the US, the CII developed 17 constructability principles using the viewpoints collected from different project owners and contractors (Russell & Gugel, 1993). The most significant difference between the CIRIA and CII principles is that the CII principles clearly highlight the important role of project owners in the decision making processes, in contrast to the CIRIA principles (Trigunarsyah, 2001). In addition, the CIRIA principles only focus on the design phase, while the constructability principles given by CII are grouped into three different project stages of “conceptual planning”, “design and procurement”, and “field operations”.

The CII constructability practices for the conceptual planning stage consist of:

1. Constructability programs are made an integral part of the implementation plan
2. Project planning actively involves construction knowledge and experience
3. Early construction involvement is considered in the development of the contracting strategy
4. Overall project schedules are construction-sensitive
5. Basic design approaches consider major construction methods

6. Good site layouts promote efficient construction
7. Project team participants responsible for constructability are identified early-on
8. Advanced technology is applied throughout the project

The CII constructability principles for the design and procurement stage include:

1. Project constructability is enhanced when design and procurement schedules are construction-sensitive
2. Designs are configured to enable efficient construction
3. Constructability is enhanced when design elements are standardised
4. Project constructability is enhanced when construction efficiency is considered in the development of specifications
5. Constructability is enhanced when module/preassembly designs are prepared in such a way as to facilitate fabrication, transportation, and installation
6. Designs promote accessibility of personnel, material, and equipment to the construction site
7. Design facilitates construction under adverse weather conditions
8. Design and construction sequencing should facilitate system turnover and start-up

The CII constructability principle for the field operation stage is:

1. Constructability is enhanced when innovative construction methods are utilised

The CIIA, as the pioneer of studying constructability concept in Australia, developed 12 detailed principles for the concept of constructability (Griffith & Sidwell, 1997). This is the most recent list of constructability principles, and is most compatible with the Australian construction industry. They are:

1. Integration: Constructability must be made an integral part of the project plan.
2. Construction Knowledge: Project planning must actively involve construction knowledge and experience.

3. Team Skills: The experience, skills and composition of the project team must be appropriate for the project.
4. Corporate Objectives: Constructability is enhanced when the project team gains an understanding of the client's corporate and project objectives.
5. Available Resources: The technology of the design solution must be matched with the skills and resources available.
6. External Factors: External factors can affect the cost and/or program of the project.
7. Program: The overall program for the project must be realistic and construction-sensitive, and have the commitment of the project team.
8. Construction Methodology: The project design must consider construction methodology.
9. Accessibility: Constructability will be enhanced if construction accessibility is considered in the design and construction stages of the project.
10. Specifications: Project constructability is enhanced when construction efficiency is considered in specification development.
11. Construction Innovation: The use of innovative techniques during construction will enhance constructability
12. Feedback: Constructability can be enhanced on similar future projects if a port-construction analysis is undertaken by the project team.

The design of these principles was based on a series of local case studies over 25 to 30 years. The literature shows that the CIIA constructability principles have resulted in more efficient planning, enhanced procurement, more effective design, easier construction methods, improved site management, stronger team work, enhanced job satisfaction and higher performance for Australian infrastructure projects. As an example, implementation of the CIIA constructability principles in a large arts and entertainments centre in Australia was reported to have reaped many benefits. First of all, there was a close interaction between the sub-consultants, consultants and project management team which resulted in better project planning and procurement. Then, contractors let the project management team assess the bidding process which resulted in more effective suggestions on design and construction alternatives; after that the poor ground of the construction area was considered during the design stage, so more efficient construction methods were used for implementation of better site works. Next, using co-ordinated cranes helped the construction team to avoid spending extra time and costs. Totally, the project was delivered four months ahead of schedule and there was around 8% of cost savings (Griffith & Sidwell, 1997).

The constructability principles are not usually applied sequentially in practice as the project phases proceed. An important development in the CIIA constructability model in comparison with the CIRIA or CII models is the concept that the CIIA model aims to guide and encourage project stakeholders to apply the constructability principles at the most appropriate time during the PLC. The relevance of each principle to the different PLC phases is presented in Table 2.

Table 2. CIIA constructability principles
(Adopted from CIIA, 1993)

Constructability Principles	Typical Project Life Cycle				
	Planning/ Feasibility	Development/Design		Construction	Post Construction
		Conceptual Design	Detailed Design		
1. Integration	Highly relevant	Highly relevant	Moderately relevant	Moderately relevant	Moderately relevant
2. Construction knowledge	Moderately relevant	Highly relevant	Moderately relevant	Moderately relevant	Not usually relevant
3. Team skills	Relevant	Highly relevant	Highly relevant	Not usually relevant	Not usually relevant
4. Corporate objectives	Highly relevant	Highly relevant	Not usually relevant	Not usually relevant	Moderately relevant
5. Available resources	Highly relevant	Relevant	Relevant	Not usually relevant	Not usually relevant
6. External factors	Highly relevant	Relevant	Moderately relevant	Not usually relevant	Not usually relevant
7. Program	Moderately relevant	Highly relevant	Relevant	Relevant	Not usually relevant
8. Construction methodology	Moderately relevant	Highly relevant	Highly relevant	Not usually relevant	Not usually relevant
9. Accessibility	Not usually relevant	Highly relevant	Highly relevant	Relevant	Not usually relevant
10. Specifications	Not usually relevant	Not usually relevant	Highly relevant	Not usually relevant	Not usually relevant
11. Construction innovation	Not usually relevant	Not usually relevant	Not usually relevant	Highly relevant	Not usually relevant
12. Feedback	Not usually relevant	Not usually relevant	Not usually relevant	Not usually relevant	Highly relevant

Legend: Highly relevant; Moderately relevant; Relevant; Not usually relevant

As presented in Table 2, the entire goal of the CIIA constructability principles is to bring construction knowledge and experience to earlier stages of the PLC for better project integration. Having a formal constructability review program during the early phases of the PLC results in the proper incorporation of designers and construction contractors, as well as beneficial teamwork throughout the project (Radtke & Russell, 1993). The principles of integration, construction knowledge and team skills focus on having the right person involved in the project selection process, mostly during the planning, conceptual and detailed design stages. The corporate objectives principle illustrates improvement of a project by consideration of both the client's corporate objectives and the project objectives, specifically during the planning and conceptual design stages. The principles of available resources and external factors show the high impact of the constructability concept by those potential influences as project stakeholders have limited control of them. The program principle considers the importance of having a schedule which is construction-sensitive as early as possible during the PLC, mostly in the conceptual design stage. The construction methodology, accessibility and specifications principles are concerned about the issues related to the final documentation of the project, as well as some construction phase considerations. The construction innovation principle focuses on consultation sessions with contractors in order to provide them with better technological facilities during the construction phase. Feedback, as the final constructability principle, is the only principle which concerns the post-construction stage of the PLC. It actually recommends the cyclic revision of the constructability program (Griffith & Sidwell, 1997).

Implementation

As highlighted above, major research has been done on the concept of constructability in the US, UK and Australia. The recent development of constructability in Australia has expanded it to include the start-up and operation stages, in contradiction to the US and UK models. The CIIA (Francis & Sidwell, 1996) suggested two types of post-construction reviews:

1. A review should be implemented soon after the construction phase is over. This review evaluates the strengths and weaknesses of the decisions made and analyses the level of constructability implementation.
2. Another type of review is the one that should be implemented periodically during the liability period. This review needs the participation of the different stakeholders involved in the O&M stage of the PLC.

The first step for implementation of constructability is to go through a constructability system process, as highlighted by Griffith and Sidwell (1995). This process is illustrated in Figure 2.

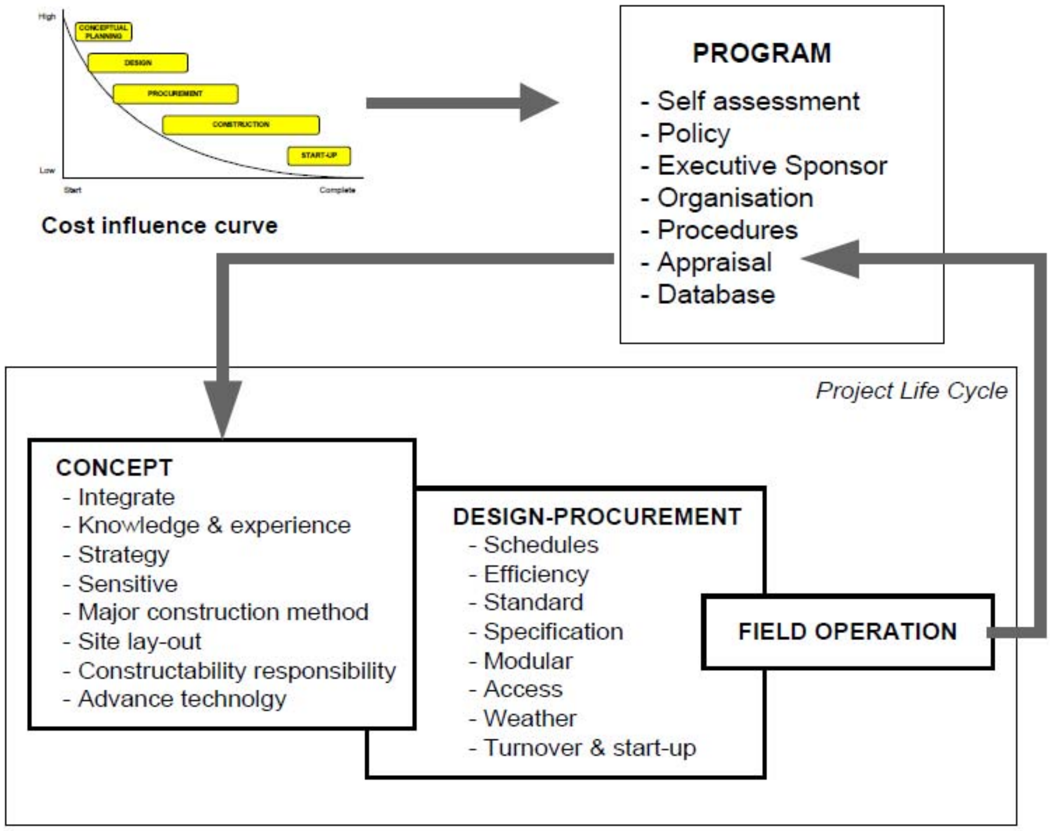


Figure 2. Constructability system
(Griffith & Sidwell, 1995)

Implementation of the constructability program within such a constructability system is not constant for different projects; however, a successful constructability program in all project types requires the following elements (adopted by Trigunarsyah, 2001):

- recognition of the abilities for early decision-making
- clear communications between top and bottom project stakeholders
- single sponsorship point
- a permanent corporate program
- use of constructability program by the clients
- designers who accept construction inputs
- early involvement of contractors and other construction staff
- easy methodologies

- lessons-learned database
- training
- early feedback

The CII (Construction Industry Institute, 1987) and the CIIA (Francis & Sidwell, 1996) recommended the following features for the successful implementation of a constructability program:

- the owner's support
- project team commitment
- training
- early construction input
- written procedures
- appraisal

A number of different approaches are suggested for the implementation of a constructability program. Russel et al. (1992) divided constructability programs into three types of corporate-level constructability, project-level constructability and constructability review programs. They also identified different approaches for incorporation of constructability at the project level that are dependent on the project type. These approaches were then classified into four major groups of:

- Formal project-level constructability programs
- Formal post-facto constructability review
- Informal application of constructability
- Untimely constructability input

Russell et al. (1992) illustrated the steps in the implementation of a constructability program, as presented in Figure 3.

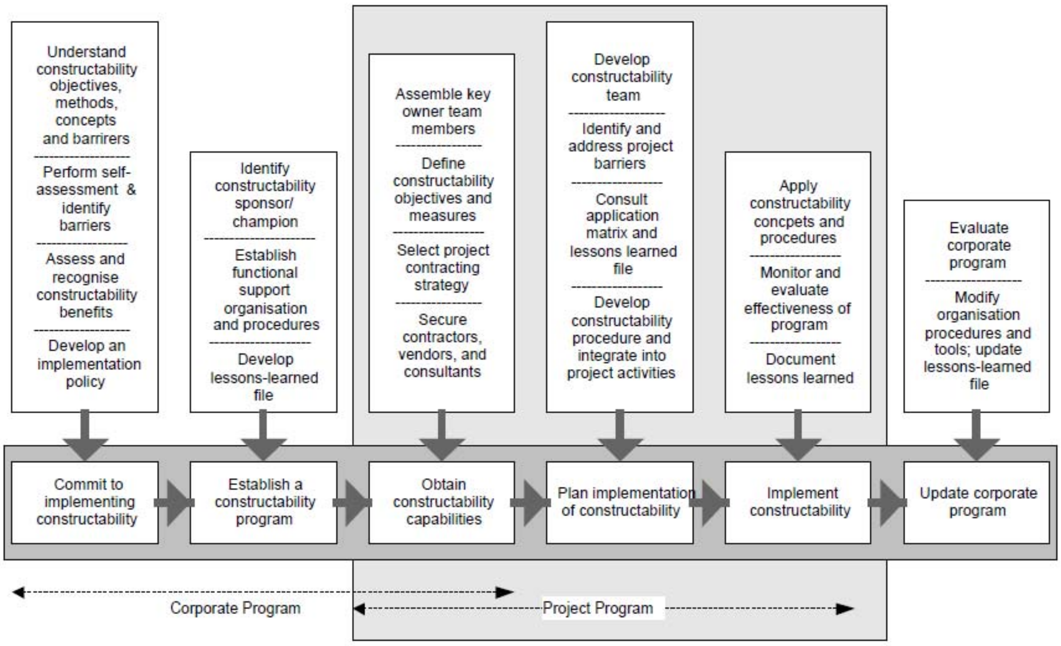


Figure 3. Overview of project-level steps in constructability implementation roadmap (Russell, et al., 1992)

Russel et al. (1992) believed that the proper implementation of a constructability program significantly reduced engineering and construction costs and time. It avoided problems through better communication, collaboration, respect, and joint efforts. The Business Roundtable (1982) in the US also estimated savings of 10 to 20 times the added cost for the project as the result of appropriate implementation of a constructability program; however, the CII argued that proposing a regular constructability review may result in defensive designers because of separation of the designers from the construction staff (Russell, et al., 1992).

In summary, the concept of constructability decreases PLC costs through early decision-making processes within the planning and design phases. The CIIA constructability principles that were developed in Australia follow the US model that considers constructability as an integral part of the PLC. Proper integration of construction staff with planners and designers plays an important role in this process, resulting in huge savings; however, the given constructability models do not cover the post-occupancy aspects of infrastructure projects.

3.3 CONCEPTS OF OPERABILITY AND MAINTAINABILITY: THE EXTENSION IDEA

The discussion in the previous section showed that many in-depth studies have been done on the concept of constructability; however, less attention has been paid to the early involvement of operational and maintenance concerns. Costs in the Post-occupancy phases include 50% to 80% of the total PLC costs (Griffin, 1993) (see Figure 4). Yet, project owners still suffer from the costs of O&M reworks in infrastructure projects. This suggests that consideration of O&M concerns in the planning and design phases would have a substantial influence on the total PLC costs and time.

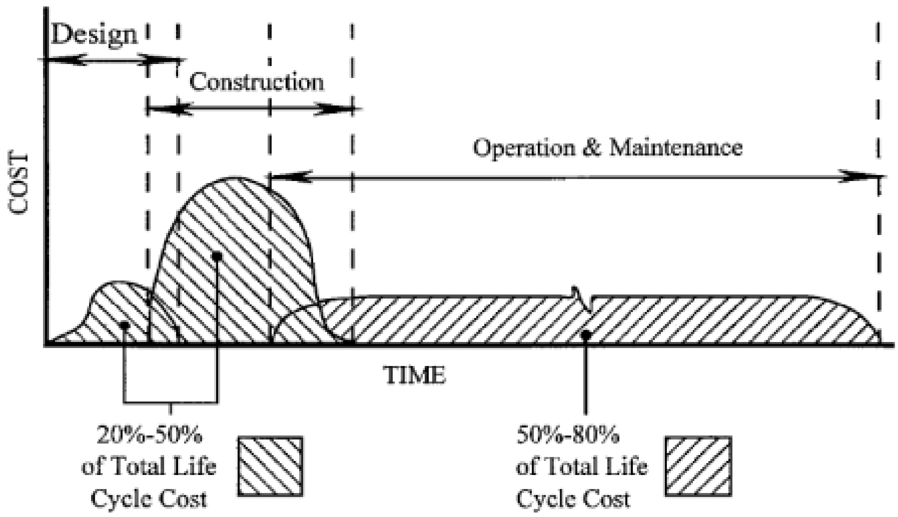


Figure 4. Life-cycle costing profile
(Griffin, 1993)

As highlighted earlier, research has proved the need to facilitate the integration of post-occupancy considerations into earlier project phases (Al-Hammad, et al., 1997; Assaf, et al., 1996; Dunston & Williamson, 1999; Geile, 1996; Ivory, et al., 2001; Lam, 2007; Russell, n.d.). Integration of the O&M phases with the planning, design and construction phases increases project owners' consideration towards post-construction concerns significantly, and avoids many O&M problems. For example, the complexity or lack of functionality of design maps is among the problems that have contributed to the unsuccessful delivery of infrastructure projects. Similarly, poor availability, accessibility, reliability or cleanability occur as the result of a lack of early consideration of operational and maintenance concerns during the planning and design phases; due to this, it is necessary to take advantage of the entire project team's experiences and knowledge in the definition of success for the project, as well as value-added gains and establishing up-front the needs of the customer/supplier for the whole project (Geile, 1996).

Operability and Maintainability

The concepts of operability and maintainability were introduced to ease the O&M knowledge transfer from the post-construction stage to the early planning, design and construction phases. These two concepts are very similar and near to each other; however, they have tended to be researched and practised separately.

The concept of operability is defined by Uwohali-Incorporated (1996) as the “ability to operate a system which is performing its intended use”. Trigunarsyah and Skitmore (2010) also defined it as ease of operation. Operability is suggested as one of the strongest factors for proper integration of the operational issues with the planning, design and construction phases; however, due to the uniqueness of this concept in every country, there is a significant need to explore it in the context of the Australian construction industry.

Targeting earlier consideration of the O&M concerns within the planning, design and construction phases, the concept of operability is very closely related with the concepts of ‘fit for purpose’ and ‘maintainability’. The design of projects should not only fit the construction of the works (Cox & Thompson, 1997), but must also fit the final uses of the project (Frame, 2003). Having a clear understanding of what upstream staff need at the early pre-construction phases helps to create designs for real project purposes (Trigunarsyah & Skitmore, 2010). The current level of project documentation lacks post-construction research , leading to extra charges for the O&M staff (Russell, n.d.).

During an operability program, the professional operation stakeholders of an infrastructure project cooperate with the planning and design members. These stakeholders check whether or not the necessary operation quality and consistency are targeted during the project planning and design or not (Trigunarsyah & Skitmore, 2010). Geile (1996) argued that planning a project without taking the clients’ considerations into every phase wastes money and that considering the customers’ viewpoints in the O&M stages can result in considerable savings during the post-occupancy stage. It can also result in infrastructure projects with a higher quality and longer life-cycle.

An infrastructure project should be designed to be fitted for its final use. To do so, recognising and defining the users’ needs and expectations for development of the project is important. Planners and designers should understand what the final project will look like, and what its ultimate purposes and uses are (Frame, 2003). Trigunarsyah and Skitmore (2010) suggested a backward-pass planning to help improvement of infrastructure projects’ operation by a more efficient design. This approach helps lower level members to find an understanding of the upstream project stakeholders of whom operation members are a major part. Such integration of O&M concerns in the planning and design phases results in projects which are designed for their particular target purposes. It also facilitates a fast and reliable knowledge transfer from professional operation staff to the planning and design teams.

Russell (n.d.) stated that successful deliverability of infrastructure projects is the direct result of a well-implemented operability concept and highly affected by availability of resources, and it can result in improved profitability (see Figure 5). The diagram in Figure 5 shows that in order to get enough availability of resources in a project, a reliable functionality and a well-designed maintenance process are needed. The concepts of operability and maintainability can considerably influence infrastructure projects through integration of O&M concerns into the planning and design stages; however, the literature suggests that their focus is still limited to the integration of O&M ideas into the planning and design only, hence limiting the impact on delivering successful projects.

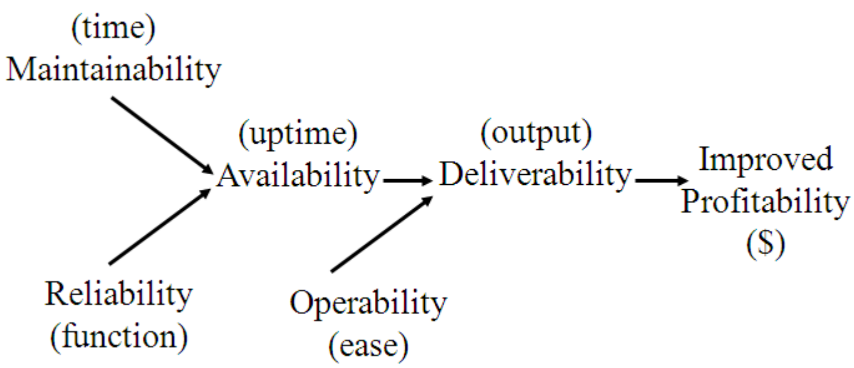


Figure 5. Operability and maintainability interrelationships

(Russell, n.d.)

The concept of maintainability is also introduced as a very closely related concept to the operability. It was initially introduced by the US military services in 1950s (Blanchard & Lowery, 1969), and it an important matter for many companies (Meier & Russell, 2000). Trigunarsyah and Skitmore (2010) defined maintainability as the "ability to maintain, or ease of maintenance". Dhillon (1999) defined it as "the measures taken during development, design and installation of a manufactured product that reduce required maintenance, man-hours, tools, logistic cost, skill levels, and facilities". Maintainability is the capability of a unit to be maintained to a condition in which it can do a specific function under known situations and using some specific processes ("ISO/IEC 2382-14. ," 1997).

Williams and Clark (1989) indicated that proper locationing of the equipment and tools is an important issue in the maintainability process. It is also very significant to care about cleanliness in the maintenance of healthcare-related projects. Caring about maintainability should be incorporated into the overall project and design processes (referred to as 'design for maintainability'); however, there are still few studies on this subject (Dhillon, 1999; Lam, 2007). Such lack of attention to the implementation of maintainability during the planning and design has led to complex and expensive maintenance (Construction 21, 1999). Ivory et al. (2001) believe that the design for maintainability concept necessitates a re-conceptualisation of the whole project and its parts, recognising the significance of integrating the maintenance issues into all the project levels. Maintainability is "the design characteristic that pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions" (Blanchard, et al., 1995). A review of the Construction 21 report by de Silva et al. (2004) highlighted eight keys for improving maintainability in infrastructure projects, as follows:

1. Life-cycle cost criterion for tendering
2. Maintainability scoring device
3. Longer liability period
4. Designers' and suppliers' position in providing data
5. Use of "design and build" (D&B) type of contract
6. Availability of life-cycle cost information

7. Having maintainability guidelines
8. Providing training sessions

Maintainability should be optimally implemented in order to result in the best expected outcomes. An optimal maintainability was defined by Dunson and Williamson (1999) as “the design characteristic which incorporates function, accessibility, reliability, and ease of servicing and repair into all active and passive system components, that maximizes costs, and maximises benefits of the expected life cycle value of a facility”.

The maintenance of infrastructure increases the life of infrastructure assets. It also reduces the costs and increases the benefits of the final delivered project (Blanchard et al., 1995; de Silva, et al., 2004), through a smoother start-up process with fewer number of reworks and mistakes (Russell, n.d.). In other words, a effective maintainability procedure contributes to the profits of the company’s owning and renting the building units (Zawawi & Syahrul, 2009). It also pertains to an easier, more accurate, safer and more economic maintenance system (Blanchard, et al., 1995). In brief, maintainability integrates the maintenance considerations into the early planning and design phases aiming to enhance the maintenance aspects of design sketches; however, it is still implemented in isolation from other integration concepts.

A facility manager provides the corporate maintainability of infrastructure projects into the design stage (Ivory, et al., 2001). Meier and Russell (2000) recommended creating a maintainability alert for both project managers and maintainability guarantors as early as possible in the project. They strongly suggested consulting with all post-occupancy stakeholders as early as possible in the PLC. Maintenance factors should be incorporated into constructability considerations in order to facilitate a better maintainability process (Dunston & Williamson, 1999), and hence can lead to lower total cost (see Figure 6). Such an incorporation of separated concepts will enable the planners and designers to see different aspects of the PLC in a single short period of time and to make their best decisions in the design sketches. This is what a successful infrastructure needs.

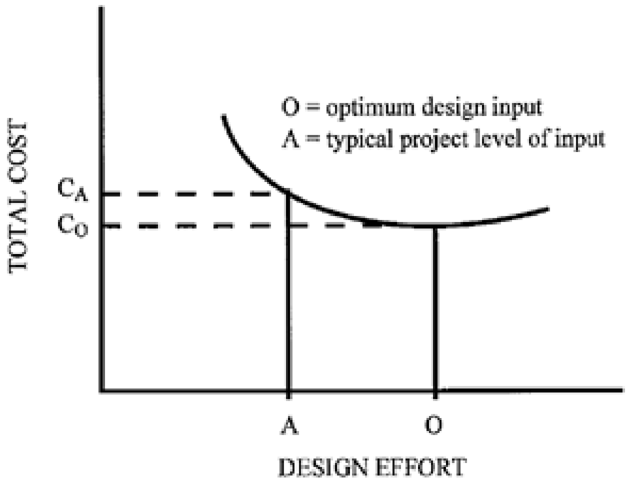


Figure 6. Optimum design input

(McGeorge, 1988)

Implementation

In terms of the implementation of operability and maintainability in infrastructure projects, few formal practices are applied, because O&M are always at the lowest level of importance in infrastructure projects in most countries (Shen, 1997). As one of the best practices, the CII maintainability research team in the US investigated a model for maintainability implementation in industry which is shown in Figure 7. It shows six milestones and their specific steps toward the complete implementation of a maintainability program.

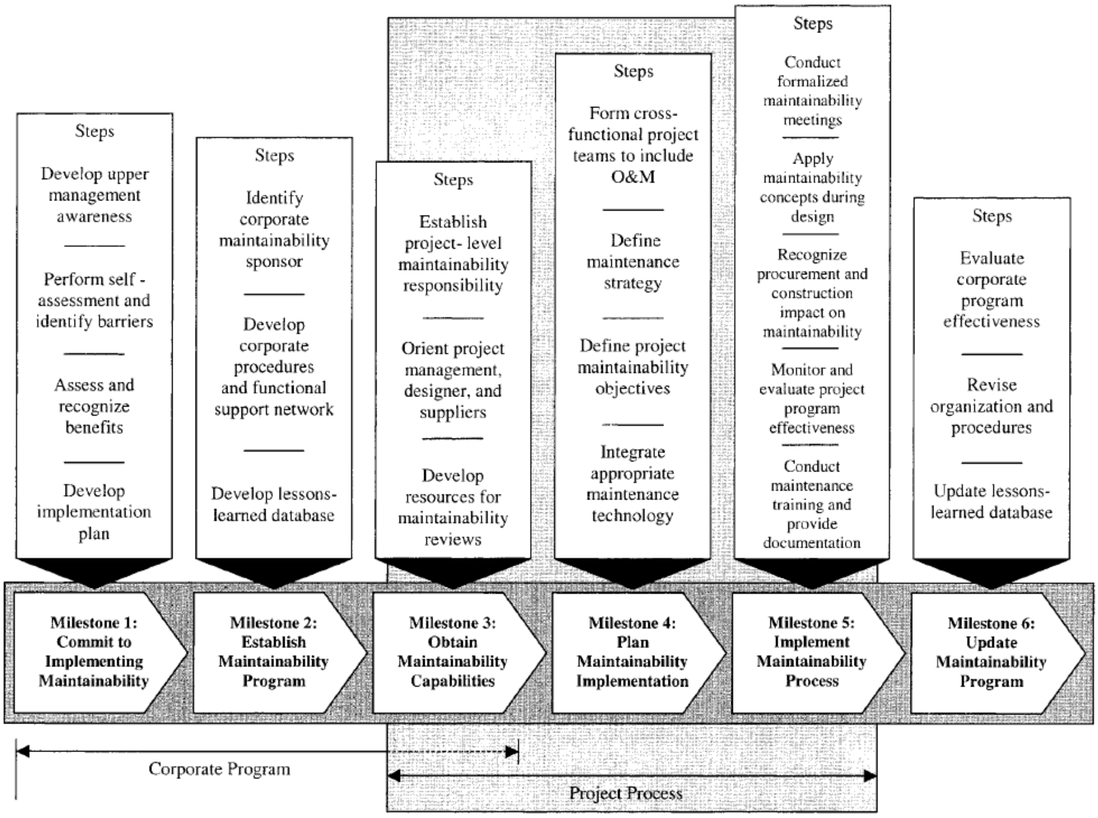


Figure 7. CII model maintainability process

A report from the former Department of Education and Science (1985) in the UK suggested that the state of maintenance and repair implementation in local schools was below the approximately required level. There is always a steeply rising need to take innovative maintenance approaches in building projects, specially in multi-faceted constructions, while the typically allocated maintenance budgets are usually lower than the estimated maintenance needs. For this reason, prioritising the implementation of O&M items is suggested as an intelligent technique to use the available resources and money in the best way (Shen, 1997). Shen (1997) identified six groups of technical, political, financial, social, economical and legal factors as the major factors for setting the prioritization in the O&M implementation of infrastructure projects. De Silva et al. (2004) reported the improved O&M of Singaporean buildings by improving maintainability at the design stage; however there are still many O&M problems that must be considered in future models. Ivory et al. (2001) suggested that having a detailed maintainability (or operability) plan at the design stage is necessary to look after the whole process in a long-term mode and enhance the integration procedure.

The costs of failures in the O&M phases of multi-faceted infrastructure projects are more significant, compared with other project types. This is because of the high costs of O&M phases and the lack of a comprehensive study which integrates all the PLC phases in a unique framework (Al-Hammad, et al., 1997; Assaf, et al., 1996; Dunston & Williamson, 1999; Geile, 1996; Griffin, 1993; Ivory, et al., 2001; Lam, 2007; Russell, n.d.). The current studies on the concepts of operability and maintainability are not sufficient yet, because there are still many O&M problems reported in the recent literature, specially related to multi-faceted infrastructure projects (see Section 2.4). From the fast technological advances of O&M facilities and equipment to the high occupancy levels of infrastructure projects, there is always the matter of a lack of effective integration between the pre- and post-occupancy stakeholders to make appropriate preventive operational decisions. There is not enough effective and efficient communication between different project personnel and, as a result, incomplete or late decisions are made by irrelevant people. The financial or human resource problems, among many other reported problems, also indicate the need for a comprehensive model which can integrate the entire PLC phases.

The Extension Idea

As discussed before, despite the potential savings, the concept of constructability in its current form is still inadequate to have an impact on reducing the O&M problems. The O&M costs and time spent in infrastructure projects in particular are much more than in small infrastructure projects; for this reason, the integration of different phases in multi-faceted infrastructure projects can save significant amounts of time and cost. The current lack of integration throughout the infrastructure PLC highlights an urgent need to develop a model that can prevent, or at least reduce, the O&M problems as much as possible. The present research seeks to bridge this gap by examining how the O&M concerns can be incorporated into the planning and design phases in multi-faceted infrastructure projects. It also examines how the three distinct, yet interrelated, concepts of constructability, operability and maintainability can be integrated to deliver an optimum outcome for successful infrastructure delivery.

It is obvious that early consideration of O&M in the planning and design phases has been largely neglected in practice. This has led to the sub-optimal delivery of infrastructure projects throughout the PLC. To minimise the O&M problems, researchers have proposed various models such as minimising maintenance costs by modelling the equipment and components (Keller & Al-Saadi, 1992), describing economic maintenance practices based on availability (Madu, 1990), optimising the time (Thomas, 1985), deteriorating and replacing attributes of a system (Valdes-Flores & Feldman, 1992), and using preventive maintenance procedures (Cooke & Paulsen, 1997; Kobbacy, et al., 1997). These models have reduced many of the existing O&M problems. They have also resulted in projects with longer life-cycles and better efficiency in O&M implementation; however, they are still insufficient as they have failed to have a comprehensive and continuing influence on the whole PLC. While these models have been specifically designed to be implemented within the O&M phase, the present research focuses on early decision-making processes within the planning and design phases with the goal to minimise the O&M failures or resolve them. Furthermore, these models also failed to cover the entire O&M aspects and components. They are actually some models that can affect the projects in a short period of time in a limited number of cases. For example, economic maintenance practices based on availability, which were firstly proposed by Madu (1990), focus on the financial aspects of maintenance practices, but not on the integration of all the post-occupancy aspects of the planning and design phases.

Constructability, operability and maintainability are the concepts that lead to the successful delivery of infrastructure projects; however, they have been implemented separately and tend to be isolated from each other (as highlighted in the discussion in the previous chapter). The constructability concept focuses only on ease of the construction phase; the operability concept focuses on the avoidance of reworks and problems in the operation phase; and the maintainability concept concentrates only on lengthening the life of projects by eliminating failures during the maintenance process. As discussed in the previous section, the concept of constructability has been very well researched, implemented, developed and practised in different countries; however, the post-construction considerations have not yet been addressed. With such a rich existing model, the researcher can use it as a platform for further investigations into the O&M phases. There are also some indications in a number of studies that predict the improvement of the operability and maintainability implementation by extending the concept of constructability to include O&M phases

(Dunston & Williamson, 1999; Geile, 1996). It is therefore necessary to examine how the concept of constructability can be extended to include the O&M phases.

By improving the effectiveness and efficiency of infrastructure projects' operation/operability and maintenance/maintainability through extension of the constructability principles, the elimination or reduction of many project reworks during the O&M phases and significant savings in the whole PLC costs are expected. Integration of these concepts through extension of the constructability principles allows all the project stakeholders' concerns to be taken into consideration during the design phase and results in more practical plans for the efficient implementation of infrastructure projects. Geile (1996) argued that by early understanding and identification of the needs of the people who are responsible for check-out, start-up and O&M, many savings will be achieved.

The next section elaborates upon how the constructability principles are to be extended to include O&M concerns. It presents a framework showing how the extension concept was developed in this research project.

3.4 A MODEL TO INTEGRATE CONSTRUCTABILITY PRINCIPLES WITH OPERATION AND MAINTENANCE

The discussion in the previous chapter highlighted that the three concepts for successful delivery of infrastructure projects – namely, constructability, operability and maintainability – have been implemented separately for a long time, reducing their impacts on the delivery process. Despite having some potential savings individually, their isolation in the current form of implementation has significantly decreased their ultimate impact on reducing the O&M problems, imposing various reworks and problems for the post-construction personnel of infrastructure projects (see Section 2.4). In the discussion above (see Section 3.3), the idea for the extension of the existing CIIA constructability model was introduced as a way to address the O&M concerns. Having that in mind, the current categorisation of O&M problems can serve as a platform for further development of the extended constructability model.

The CIIA constructability principles do not address post-occupancy concerns and there is a significant need for extension of the existing principles to a more comprehensive model, covering O&M stages in addition to what the CIIA constructability model covers. It should be noted that the proposed model integrates the operability and maintainability principles with the constructability principles based on the current practices implemented by different Australian project stakeholders, aiming to resolve the O&M problems.

The proposed extended constructability model, called the construction, operation and maintenance ability model, includes a number of principles covering both pre- and post-construction phases (see Figure 8); however, it is highly expected that most of the newly designed principles for better implementation of the operability and maintainability concepts target the pre-construction phases of planning and design, because earlier decisions can make more savings.

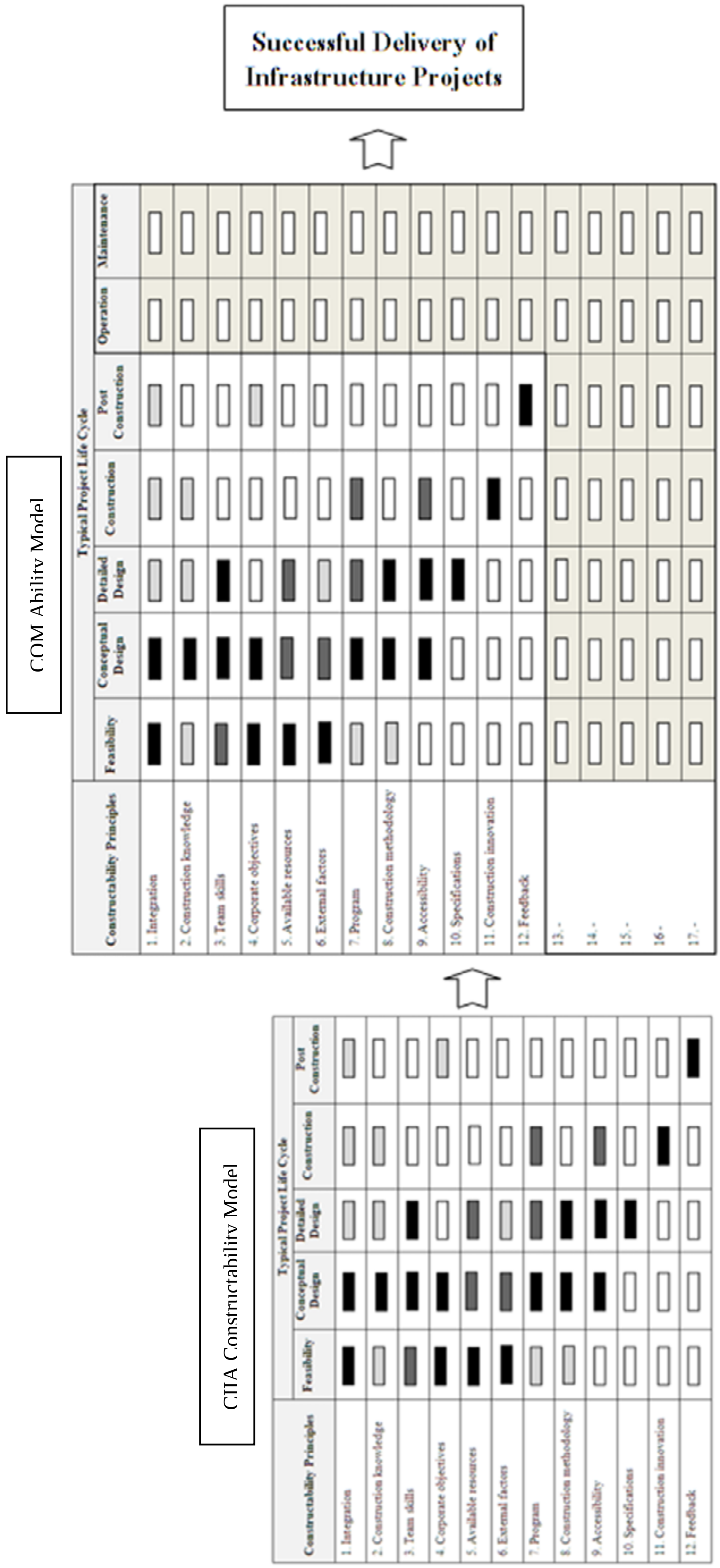


Figure 8. Conceptual framework

Chapters Two and Three of this study explained the project objectives, and hence formed the foundation for the research study. The next chapter presents the research method adopted in this study. These methods were applied to answer the two main questions of this project, as follows:

1) What are the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects?
2) How can the operability and maintainability be integrated with constructability for the successful implementation of infrastructure projects?

3.5 SUMMARY

This chapter presented the definitions, principles, implementation and benefits of the constructability concept. Then, it explored the definitions and models given for the operability and maintainability concepts, and highlighted that the concept of constructability should be the basis for integrating the three concepts by extending the constructability principles to include the O&M phases. After that, it presented a framework to integrate the constructability principles with O&M ideas.

Considering the uniqueness of the construction industry in every country, it is important to check how the O&M concerns of the Australian infrastructure projects are currently integrated into the planning and design phases. In addition, it is significant to explore how the real-world Australian O&M stakeholders address these concerns. Only then can a method for extension of the constructability principles be proposed.

A number of interviews from rich data-points within a comprehensive case study are proposed to collect information about the existing O&M problems and the practices attempting to address them in Australian infrastructure projects. In the next two chapters, this is followed by an assessment of the responses, which were gathered with the aim to inform the design of principles for the effective and efficient implementation of operability and maintainability. These principles serve as a basis for further integration of the O&M ideas into the CIIA constructability model. Lastly, verification of the principles of the extended constructability model through interviews with different Australian project stakeholders is discussed.

Chapter 4: Research Design

4.1 INTRODUCTION

The discussion in Chapter 2 demonstrated that separation of the constructability, operability and maintainability concepts has isolated the experience and knowledge of project professionals in different phases. This has prevented the proper implementation of activities during project phases, resulting in the lower than expected level of successful delivery of infrastructure projects. The discussion in Chapter 3 explored the three concepts in detail, and suggested a framework to integrate the concepts through extension of the existing CIIA constructability model as the basis for including the O&M considerations. Following that, this chapter discusses the case study approach used in this study to illuminate the central question of how the constructability concept can be extended to cover O&M phases resulting in the successful delivery of infrastructure projects. The case study research approach enhances exploration of principles for effective and efficient implementation of operability and maintainability in infrastructure projects and results in the development of an extended constructability model, covering both construction and O&M concerns.

This chapter begins with a description of the philosophical position in Section 4.2. It provides clarification on the epistemological stance adopted in this research. Section 4.3 presents the research flow, together with the research aim and questions. In Section 4.4, the process of selection of the research method is presented, further illustrating a detailed rationale for using the case study method and use of multiple cases within the case study. Section 4.5 describes the research steps, explaining the Case Study Protocol to clarify the procedures adopted to select and conduct the case study. This is then followed by a discussion of the model development describing the development of the extended constructability model and demonstrating how the proposed principles are to be verified. Following this, Section 4.6 introduces the chosen data analysis approach and software; this is a brief introduction only, as the analysis techniques are described later in more detail in Chapter 5. This chapter concludes with a presentation in Section 4.7 of how the research quality factors including validity, consistency and trustworthiness, and generalizability were considered all through the research process. Finally, Section 4.8 summarises this chapter.

4.2 PHILOSOPHICAL POSITION

Prior to the conduct of research, it is very important to be aware of different philosophical frameworks that can affect how the research will progress. A philosophical framework is defined as a driving power behind the aim of a study (Sarantakos, 1998). A philosophical framework shows the available techniques and methods in addition to the general perception of social and reality relations in the research. Thus, it is necessary to consider some assumptions about the formulation of a research approach, before selecting a specific approach. Hirschheim and Klein (1989) named these assumptions a paradigm. Sarantakon (1998) defined a paradigm as "a set of propositions to explain how the world is perceived; it contains a world view, a way of breaking down the complexity of the real world, telling researchers and social scientists in general 'what is important, what is legitimate, what is reasonable".

In other words, the paradigm has implications for different existing choices of the research method, data collection technique and analysis (Too, 2009). Sarantakos (1998) and Guba (1990), similarly, argued that the paradigm guides the research process by influencing the choice of methodology. Sarantakos (1998) divided the existing paradigms into three categories of positivistic, interpretive and critical. This categorisation is based on how to recognise the reality, how to perceive human beings, and what to consider as nature or science.

Sarantakos (1998) and Neuman (2006) provided a useful review of the three categories of paradigms. The "positivistic paradigm" believes that the social world is independent of humans, although it is measurable, objective and in order. Positivists see human beings as individuals guided by laws, so freedom does not have any place in their belief. They think science relies on strict rules, so they approach research as deductive in nature by investigating questions requiring experiential testing. The "interpretive paradigm" sees human beings as central to reality and the social world, because it believes reality is in the minds of humans, and is created through social interactions and relationships. Interpretive research investigates how people make sense of their world, so interpretive researchers try to understand the meanings and their interpretations by people. This paradigm leads this research to follow an inductive research path where the researcher is connected to the participants in a research project. Lastly, the “critical paradigm” sees reality as created by powerful humans in particular. This paradigm believes that reality is not ordered; it is dictated by a specific group of people conditioning the others to perceive things as they want. Critical researchers think that people are restricted by more powerful people from having enough capability for creativity, preventing them from grasping their real potential. In brief, critical science focuses on removing the wrong ideas about the powerful people or systems that control human beings in societies.

The present research aims to extend the concept of constructability to include O&M concerns resulting in the successful delivery of infrastructure projects. It aims to explore the O&M phases to identify some principles for better involvement of the O&M knowledge and experience in the earlier project phases. To come up with such principles, it is important to assess how people have faced the relevant phenomena and events during the life of infrastructure projects. It is necessary to understand the insights of staff into their daily problems, day-to-day activities and how they think to confront with the problems. In brief, this study aims to realise how the research participants make sense of their own reality. This is what an interpretive paradigm relies on; therefore, this research can be considered as following an interpretive research paradigm approach. In addition, to gather as much evidence about reality as possible (Denzin & Lincoln, 2000) and to gain a richer perspective of what happens in the real world (Trochim, 2006), this research targets multiple data-points as sources of evidence including interviews with respondents from different cases, and a review of documents.

4.3 RESEARCH FLOW

The research problem addressed in the current study was the lack of the proper integration of ideas from different PLC phases resulting in project success being compromised. Such separation among the concepts of constructability, operability and maintainability has resulted in many reworks and extra charges in the delivery of infrastructure projects. The previous research on the concept of constructability appears to be insufficient to solve the existing project delivery problems, as it only covers pre-occupancy concerns. Considering the research problem, a broad review of literature in different fields was proposed to search for the post-construction issues. As a result, a research framework was suggested to integrate the constructability principles with O&M, targeted to achieve the optimum successful delivery of infrastructure projects. To accomplish this target, the following questions were designed to be answered in this research:

1) What are the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects?
2) How can the operability and maintainability be integrated with constructability for the successful implementation of infrastructure projects?

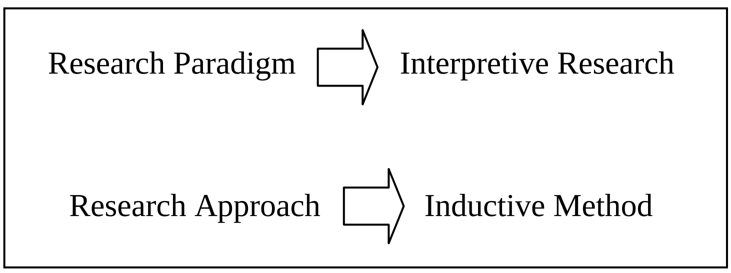
The discussion in Chapter 3 indicated that existing studies are inadequate to address the research questions by applying a theory testing approach. Lack of a model integrating all project phases, insufficient research exploring the various problems in the O&M of infrastructure projects, as well as the existence of a widely practised model for the concept of constructability, led the research project to use a mix of deductive and inductive approaches. Furthermore, this research used a qualitative investigation technique, as proposed by Eisenhardt (1989), to collect rich data from different data-points.

Research can be conducted through deductive or inductive methods (Cavana et al., 2001; Sutrisna, 2009). Deductive researchers start with theories and then move to evidence (Cavana, et al., 2001); however, inductive research leaves the mind open to any possible result through detailed observation and then moves to building theoretical opinions (Sutrisna, 2009). Perry (1998) believed that doing a pure deductive or inductive research approach prevents the researcher from using existing knowledge, or may prevent the development of novel theories. In the present research project, the concepts of constructability, operability and maintainability played an essential role in the design of the research framework and the selection of the data collection technique. Moreover, as shown in the discussion in Chapters 2 and 3, the current level of knowledge still fails to address the identified research gap. For this reason, this study used a mix of deductive and inductive reasoning, although the main focus was on the inductive reasoning. An inductive approach was more prominent in this study because the problems outlined for the O&M of infrastructure projects have not yet been well-established and analysed. Such complexity of the current knowledge on O&M problems precludes the use of a purely deductive method.

This research extends the concept of constructability to include O&M through an inductive theory building method. This approach uses one or more cases of research to build propositions and constructs and is perfect when there is little knowledge about an issue or phenomenon (Eisenhardt, 1989). The inductive theory building method was chosen because firstly there is limited knowledge about the O&M of multi-faceted infrastructure projects within the Australian construction industry; secondly, the current level of knowledge is still insufficient for using a pure deductive technique; and lastly, use of an inductive theory building approach increases the chance of creating a new theory and justifies its validity and testability. In brief, the major inputs to this study are the viewpoints taken in the cases of research and also the existing constructability concept; the process is an inductive study on the collected data; and the output is an extended constructability model that includes O&M considerations.

One of the major limitations of the inductive theory building approach is the need for the collection of data from multiple data-points, rather than a single case (Dyer & Wilkins, 1991). The collection of data from multiple data-points provides an environment to achieve a thinner layer of data from more people in different positions, allowing more strengthened findings. Consequently, this research collected data from different sections of Queensland Health (QH), helping to make better comparative logics and as a result leading to stronger reasoning for the theory building process.

The inductive and deductive research approaches work like mirrors of one another, as stated by Eisenhardt and Graebner (2007); so the model developed in this project, using the inductive theory building technique, can easily be tested by a future deductive theory testing approach.



4.4 RESEARCH METHOD

Having selected the research framework, paradigm and approaches to be used, the selection of the research method was the next step. The research method of a project connects the researcher to specific methods of data collection and analysis (Denzin & Lincoln, 2000). The research method as a strategy keeps the paradigms of analysis in movement (Too, 2009).

For the purpose of this research, the case study method collecting data from multiple data-points was adopted to develop the extended constructability model. Two rounds of interviews, plus a review of relevant documents, were carried out to collect data, and the data was then analysed using qualitative analysis techniques. A summary of the research questions and objectives, including their specific selected research method, data collection method and the type of data analysis technique used, is presented in Table 3.

Table 3. Selection of research method

No.	Research Question	Research Objective	Research Method	Data Collection Method	Data Analysis
1	What are the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects?	To identify the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects.	Case Study	• 1st Round of Interviews • Review of Documents	Qualitative
2	How can the operability and maintainability be integrated with constructability for the successful implementation of infrastructure projects?	To develop a model that extends the concept of constructability to include operability and maintainability considerations for the successful implementation of infrastructure projects.	Case Study	• 2nd Round of Interviews	Qualitative

The first round of interviews identified the O&M problems in the current Australian working environment, focusing on those stakeholders dealing with the O&M phases of infrastructure projects. The review of documents enriched the data collected from the interviews to enable a better analysis of the existing practices addressing the O&M problems during the delivery phases of infrastructure projects. It also enhanced analysis of the data to identify the principles for efficient and effective implementation of operability and maintainability.

The second round of interviews targeted a wider range of respondents from different project stakeholder groups to verify the extended principles of the constructability concept. This process confirmed whether or not the results taken from the first round were correct. Then it verified whether or not the views of the O&M staff regarding the extension of the CIIA constructability principles were accepted by other project stakeholders. Different methods could be used for verification of the proposed principles, but the need to manage the available time by using a faster and less expensive method led this research to use another round of interviews, as the connections with the cases of study were already arranged for the first round of interviews. A detailed reasoning for the selection of the current verification method is presented in the Section 4.5.3.

4.4.1 Rationale for Using Case Study Method

Evans (1995) stated that there is a significant need to provide the rationale for the selection of every single method before starting to describe the method, because it may result in some failures through the research process. For this reason, this section provides the reasoning for the selection of the case study as the research method of this project.

The term “case study” as a research method is a rich description of particular instances of a fact which are based on different sources of data (Yin, 2003). Eisenhardt (1989) stated that a case study is a significantly efficient strategy when the research aims to understand dynamics presented in single settings. Case studies can be used for different purposes, including obtaining descriptions (Kidder, 1982), testing theories (Anderson, 1983; Pinfield, 1986) or building theories (Eisenhardt & Graebner, 2007; Gersick, 1988).

There are many benefits identified in the case study method by different researchers. The case study is suitable when the investigator has limited or no control over the events (Yin, 2003). It can also measure and control variables precisely (Edwards, 1998). It is more desirable to use case studies when the available theory seems inadequate and the researched topic needs more novelty (Eisenhardt, 1989). In other words, it is suitable to use when there is no feasible statement that answers the research questions. The case study method also lets the researcher ask penetrating questions aiming to collect rich data (Gable, 1994).

Due to the lack of successful delivery of infrastructure projects as the result of the isolation of constructability, operability and maintainability concepts, this research aimed to develop some propositions in order to extend the constructability concept to include O&M considerations. In doing so, it was necessary to examine the dynamics that exist among different stakeholders who are responsible for operating and maintaining infrastructure projects. These dynamics, as the main principles for the effective and efficient implementation of operability and maintainability concepts, are not within the control of the researcher. Current research on constructability concept is also inadequate to cover O&M concerns. For these reasons, the case study method was considered to be suitable for the development of the extended constructability model.

Yin (2003) also stated that the case study method is perfect for research questions starting with ‘how’. As the main question of this research was to find out how the operability and maintainability can be integrated with constructability for successful implementation of infrastructure projects, this is a further reason indicating that the case study was suitable for this research project.

Lastly, Rowley (2002) indicated that when there is the matter of making propositions from explanatory or descriptive studies, the case study is a suitable method for this purpose. In this study, the researcher looked into all the earlier evidence such as literature, interviews, documents, and guidelines in order to design some targeted propositions. For this purpose, the case study method could easily facilitate such an environment for descriptive or explanatory analyses in order to enhance the model development process in the current research project.

4.4.2 Use of Multiple Data-Points within the Case Study

Building the theories from different data-points results in theories which are testable, precise and interesting (Bazely, 2007; Eisenhardt & Graebner, 2007). In order to consolidate the work and create theoretical constructs, it is highly recommended to use multiple cases for inductive theory building studies (Benbasat et al., 1987; Eisenhardt, 1989). Although a single case can richly describe a phenomenon (Sigglekow, 2007), multiple respondents provide a considerably stronger foundation for the theory building process (Yin, 2003), and allow for a wider investigation of the research questions (Eisenhardt & Graebner, 2007). Having multiple cases also helps the researcher to make comparisons in order to prevent building any theory which is idiosyncratic to a single case (Eisenhardt, 1991); moreover, it improves uniformity of the findings (Gable, 1994). There is no need to select representatives for the cases of research, because the main goal is building the theories, not testing them (Eisenhardt & Graebner, 2007). Therefore, this research collected data from multiple data-points in multi-faceted infrastructure projects in order to come up with an accurate extended constructability model. As a result, the final model would be more comprehensive and testable.

Although the case study is a perfect method with many benefits, it still has some limitations. For example, it may be hard to generalise the findings of case studies to different settings (Amaratunga & Baldry, 2001). However, the present study did not aim to achieve global findings, and the final extended model can simply be tested to match with broader settings in future studies.

4.5 DESCRIPTION OF RESEARCH STEPS

The previous section explained why the case study was chosen as the research method of this study, and why multiple data-points were accessed in the process of data collection. This section elaborates on the different operationalising steps of the current research project through introducing the case study protocol and justifying selected methods of data collection for model development and verification steps.

4.5.1 Preparation of Case Study Protocol

Reliability of the findings or, as suggested by Yin (2009) and Sutrisna (2009), consistency and trustworthiness, are among the most important factors of good research studies. Reliability removes bias and errors during the research process.

Preparation and use of a case study protocol can simply facilitate proper reliability (Too, 2009). The case study protocol is an important step in the implementation of case study research projects. It can significantly increase the stability of research, especially for case studies from multiple data-points (Yin, 2009). The case study protocol keeps the researcher focused on the main aim of study through clarification of the instruments and procedures used. A copy of the current research case study protocol is attached in Appendix F. It includes an introduction to the role of the protocol, an overview of the case study, the interview questions, interview session times and schedules, data collection procedure and data collection plan.

4.5.2 Model Development

The first step in model development was to design the operability and maintainability principles that would bring O&M stakeholders' ideas into earlier project phases. The main purpose of this step was to (1) identify O&M problems, (2) identify current practices in addressing O&M problems, and (3) design the key principles for the effective and efficient implementation of operability and maintainability concepts in the delivery of infrastructure projects. The next step was to extend the constructability concept to include the operability and maintainability principles. This step was designed to answer the second research question: how to integrate the constructability concept with the operability and maintainability principles for the successful implementation of infrastructure projects.

The case study method provides the opportunity to use different sources of evidence (Yin, 2009). The use of multiple data collection approaches also results in a situation in which the strengths of one method can cover the limitations in the other (Gillham, 2000). For the purpose of this research, two rounds of interviews and a review of the documents were proposed. The first round of interviews and a review of the documents collected the necessary data for the first step of model development which was to design the operability and maintainability principles. Then, the operability and maintainability principles were integrated with the CIIA constructability principles. The second round of interviews was for model verification purposes, as explained in the next sub-section. The data collection techniques employed for the purpose of the model development are now discussed in more detail.

First round of interviews

An interview was the selected method for the first step of the model development process, and aimed to collect the data to design the operability and maintainability principles. An interview is simply defined by Kahn and Cannell (1957) as "a conversation for a purpose". An interview has been described as "a highly efficient way to gather rich and empirical data, especially when the phenomenon of interest is highly episodic and infrequent" (Eisenhardt & Graebner, 2007). Eisenhardt and Graebner (2007) stated that an interview is a proper method for limiting bias through talking with different informants, and helping to see a phenomenon from diverse perspectives.

This research targeted QH for data collection purposes, and the participants who agreed to be involved in the first round of interviews were grouped into two main categories. The first group involved the QH district-level units, including hospitals, laboratories and health centres. In this group, data were collected from the Gold Coast University Hospital (GCUH), Royal Brisbane and Women's Hospital (RBWH) and Toowoomba Hospital (TH). The second group involved the corporate units of QH including the Hospital Infrastructure Development and Delivery (HIDD) team, Asset Management Services Unit (AMSU), Centre for Healthcare Infection Surveillance and Prevention (CHRISP) and Capital Delivery Program (CDP) team. Cooperatively, these two sections manage QH infrastructure projects starting from project initiation and planning to project O&M stages (see Appendix E for job titles of the respondents).

The interviews were conducted over a period of three month from January to April 2012. An appointment for an approximately one hour semi-structured interview was made with each person who had agreed to participate in this research project. The 'Participant's Information for QUT Research Project' and the 'Consent Form' were sent to respondents for perusal before conducting the interviews (see Appendix A for the sample of these documents). The face-to-face interviews were designed in a way that collected the required data in a single session (see Appendix B for the sample of the interview questions). It would be difficult and time consuming to reschedule the meetings, because O&M professionals are busy people who are usually required to be actively present in their workplace in order to resolve maintenance issues without delay. Most of the interviews took around one hour, while a few interviews took a bit longer. A digital voice recorder was used to record the interviews after obtaining the respondents' permission. The interview recordings were all transcribed and entered into the NVivo 8.0 software for the analysis purposes.

Table 4 presents a summary of the research cases, including the age of each case and the number of interviewees related to each case in both the district and corporate sections of QH. It shows the three hospitals at the district level that were selected based on when they were built. There were three projects with three different ages. The GCUH was the most recent one and was still under construction. The RBWH was renovated around 10 years ago and TH was the oldest one.

Table 4. Case profile

	Queensland Health						
Sections	**District**			**Corporate**			
Hospital / Organisations	Toowoomba Hospital	Royal Brisbane and Women's Hospital	Gold Coast University Hospital	Asset Management Services Unit	Centre for Healthcare Related Infection Surveillance and Prevention	Capital Delivery Program	Hospital Infrastructure Development and Delivery
Year Built/ Developed	1859 (build) No major development	1938 (built) 2003 (major development)	Under construction	-	-	-	-
Number of Interviewees	2	2	1	1	1	1	2

The discussions during the interviews were formed around the following open topics through the semi-structured questions (shown in Appendix B):

- The problems affecting the O&M of infrastructure projects
- Current practices addressing the O&M problems during the delivery phases of infrastructure projects

- Principles for effective and efficient implementation of operability and maintainability

In order to refine the principles to enhance operability and maintainability implementation, a number of documents and guidelines were also reviewed. These documents and guidelines are publically available and regularly revised. They included:

- Capital Infrastructure Minimum Requirements (CIMR)
- Capital Works Management Framework (CWMF)
- Maintenance Management Framework (MMF)
- Strategic Asset Management Framework (SAMF)
- Design Decision Making Process (DDMP)

It is important to select appropriate cases of study and design the most suitable interview questions at the preparation stage. It is also important to verify these questions by conducting a pilot test before implementation of the main data collection stage. It should also be noted that the samples for interviews did not need to be representatives of health centre projects, as the main purpose of this research was the development of a model, not testing a model (Eisenhardt & Graebner, 2007). Last but not least, Denzin and Lincoln (2000) stated that interviews should be conducted at the participants' places of work to prevent the possibility of skewed findings caused by unfamiliarity.

This research conducted semi-structured interviews with the respondents in which some open-ended questions were arranged in a logical order. Semi-structured interviews usually take longer than other interview types, helping the interviewer to spend more time with respondents. It also focuses more on the respondents' perspectives, rather than the investigator's viewpoints. The interviewer uses language that is natural to the respondents to help the respondents feel more relaxed, feel that they are in an equal position to the interviewer, and not under the control of another person (Burns, 1997). This type of interview prevents any ambiguities during the collection of the required data through the use of semi-structured questions. In the present study, it also helped the O&M-related stakeholders to feel free to mention all their concerns about existing problems during the performance of their work (Cavana, et al., 2001).

In terms of the interview questions, they were designed and used in a way that they could be changed in either a planned or unplanned way. This was done in order to provide an environment for the respondents that was flexible and could enable them to reflect their real understanding of the current situation. This contributed to the validity and precision of the collected data.

Review of documents

According to Yin (2009), a review of documents offers evidence to support the data from other sources. In this research, the data taken from the first round of interviews was also supported and compared with data from a review of relevant documents. This method provided more insights, as many issues might simply not have been raised during the interviews.

These documents were publically available on the QH or Department of Public Works websites, and there was no need to apply for permission to access them. The documents are identified in detail in the next chapter.

4.5.3 Model Verification

Analysis of the findings from the first round of interviews with O&M-related stakeholders and the review of the documents resulted in the formulation of some propositions helping to extend the constructability principles that cover O&M concerns as well as pre-occupancy considerations. These principles needed to be verified, taking the opinions of other project stakeholders into consideration. To achieve that, the second round of interviews was carried out.

Second round of interviews

The second round of interviews was proposed to verify the principles of the extended constructability model. Similar to the first round, several interviews were proposed with several data-points (10 respondents) to limit the bias regarding the designed principles. These data-points were from different stakeholder groups who were involved in the projects, and not only O&M-related professionals. This was because the principles of the extended model should be beneficial to everyone in a project, and all the project stakeholders' comments on the principles should be taken into consideration.

The researcher took a copy of the extended constructability model into each interview session, and the respondents were asked to make comments on the principles. One main single question was asked to start the interview:

> Do you agree with these statements or not? ...... Why?

The respondents' comments could direct other interview questions, with the aim to verify the principles of the extended constructability model.

The verification process ensured that the final model was accepted by all project stakeholders and no directive intention or private/group motives entered into the model development process. Any probable bias regarding the propositions would be removed, and refinement/adjustment of the final model was proposed.

4.6 DATA ANALYSIS APPROACH

Data analysis is the process of examining, grouping, testing or recombining different quantitative or qualitative information to address the main research questions (Yin, 2003); however, analysis techniques of case studies are not well studied, developed or practised (Yin, 2009). To achieve a smoother data analysis process for case studies, Yin (2009) advised that the focus should be on the main research questions. This helps not to avoid being distracted by other data.

Data analysis has three main processes: (1) data decrease, (2) data show, and (3) conclusion/verification (Miles & Huberman, 1994). The collected data from the first round of interviews and review of the documents were analysed using QSR NVivo 8.0 software, which is expert software for qualitative analyses. This software helped to reduce the collected data and present it in the simplest possible way. It also provided a faster coding process of ideas from the interviews and documents, preventing delays during the data analysis (Bazeley & Richards, 2000). It allowed the researcher to code a specific section of texts multiple times; and lastly, it saved the references to the texts separately, preventing any interruption with the original file. Creswell (2007) stated that the use of such computer software for data analysis purposes has many benefits, such as quick access to the data, easy location of the data, easy to find details in the data, visualisation capabilities, and easy retrieval of memos. In brief, this software is perfect for breaking the data into some codes, and it makes the qualitative analysis process much faster. For this reason, the researcher decided to use QSR NVivo 8.0 software for the current study.

For the purpose of data analysis, two types of coding processes, called descriptive coding and pattern coding, were proposed. The purpose of coding texts is to get access to the main ideas and assess what is going on in the collected data. Such a step also enables unstructured data to be transformed into ideas. It links the collected information to ideas, or vice versa (Richards & Morse, 2007). From this point forward, it clarifies the coding process for the qualitative data analysis used in this chapter; it elaborates on the type of coding methods used for the analysis of the collected qualitative data. It then explains the selected coding techniques and clarifies the analysis process. These techniques were used for analysis of the results as discussed in this chapter and the next chapter.

According to Saldana (2009), a code in qualitative inquiry "is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data". A coding process was used to classify the qualitative interview data into a particular order in order to make constructs from a large amount of collected data. After that, a codifying/categorising process was used to make the codes a part of the total classification. Grbich (2007) stated that this process allows data to be "segregated, grouped and re-linked in order to consolidate meaning and explanation". In brief, the coding process was used to better organise the similarly coded data into trees. Saldana (2009) believed that when someone recodes the existing codes, the data becomes more refined. That is why this research implemented rounds of recoding during the analysis stage.

From this point forward, the main aim of the coding and categorising process was to construct the theories based on the refined data. Saldana (2009) explained that when the categories are all ready, the final stage is to compare the categories and check the reality of the data and move forward to achieve a well-constructed scheme, design or theory. Corbin and Strauss (2008) explained that "our ability to show how themes and concepts systematically interrelate leads toward development of theory". Saldana (2009) illustrated this process in a diagram shown in Figure 9. This research also used the same method for analysing the collected qualitative data.

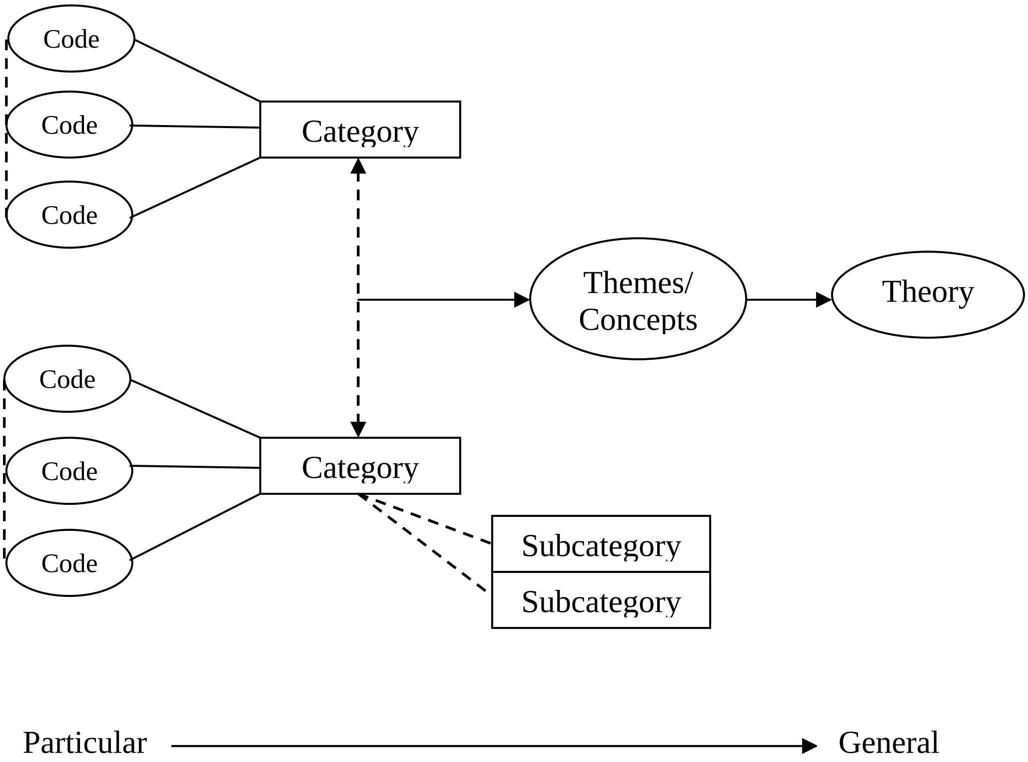


Figure 9. Streamlined code-to-theory model for qualitative inquiry
(Saldana, 2009)

Selection of the best coding technique for each study depends on the research construct. Since each research is unique, the analytical approach is also unique (Patton, 2002). Saldana (2009) noted that no-one can claim final authority on the best way for coding data. Saldana (2009) continued that depending on the nature and goals of every single research study, one or multiple specific coding techniques will suffice. Some researchers believe that more than one coding methods should be explored in every single study to enhance accountability and the depth of findings (Coffey & Atkinson, 1996; Leech & Onwuegbuzie, 2005; Mello, 2002). For this reason, this research used first and second cycle coding processes that are briefly explained as follows:

First Cycle Coding: Descriptive Coding

The coding process is cyclical rather than linear. The first cycle happens during the initial coding of data and can be done through different techniques. The first cycle coding can range in magnitude from a single word to longer passages of texts (Saldana, 2009). One of the generic methods that is highly recommended for the purpose of first cycle coding is the "descriptive coding" method. This technique is suitable for nearly all qualitative methods, particularly for beginning researchers learning how to code data. This method is perfect to be used for studies that focus on a variety of data forms such as document reviews, interviews and journals articles (Miles & Huberman, 1994; Saldana, 2009; Wolcott, 1994). This method was selected as the first cycle coding technique for the present study, because it fulfilled the highlighted needs of this research.

Descriptive coding helped the researcher to shape the initial collected data and analyse basic topics of the collected data. Turner (1994) stated that this is like the "basic vocabulary" of the data for further analysis. To do this, the interview transcriptions were reviewed and coded accordingly. Whenever needed, descriptive codes were assigned as sub-codes in more detail. The general codes were named as the "parent" while the sub-codes were called "children", as suggested by Gibbs (2007). This provided an organisational grasp of the study; moreover, it provided an essential groundwork for the second cycle coding. The descriptive coding categorised the problems affecting the O&M of infrastructure projects and analysed the existing practices to address the problems.

Second Cycle Coding: Pattern Coding

Second cycle coding is more challenging because it requires the application of abilities and skills for prioritising, categorising, integration and theory building. It is an advanced method of re-categorising and refining the transcriptions. Its primary goal is to develop a sense of theoretical organisation from the first cycle codings (Saldana, 2009). "Pattern coding" is among the suggested methods for second cycle coding. According to Miles and Huberman (1994), pattern coding is appropriate for the second cycle coding, the development of major themes out of data, the search for rules and explanations in data, and the formation of theoretical constructs and processes. It matched to the aim of this study, and as a result it was selected for analytical purposes for the later round of data analysis as reported in the next chapter.

Pattern coding helped the researcher to review the first cycle codes to assess their commonality and check their patterns. Pattern coding was also used to develop statements that described the theoretical constructs of the data that are discussed in the next chapter. Pattern coding was used to categorise the professionals' views about improvement of operability and maintainability implementation within health infrastructure projects and uncovered some O&M principles that are presented in the next chapter.

As an example, there were different passages of the interviews' transcriptions that were initially descriptively coded as shown in Figure 10. After researcher reflection using the pattern coding technique, the final pattern code for different descriptive codes of the problems was created and selected.

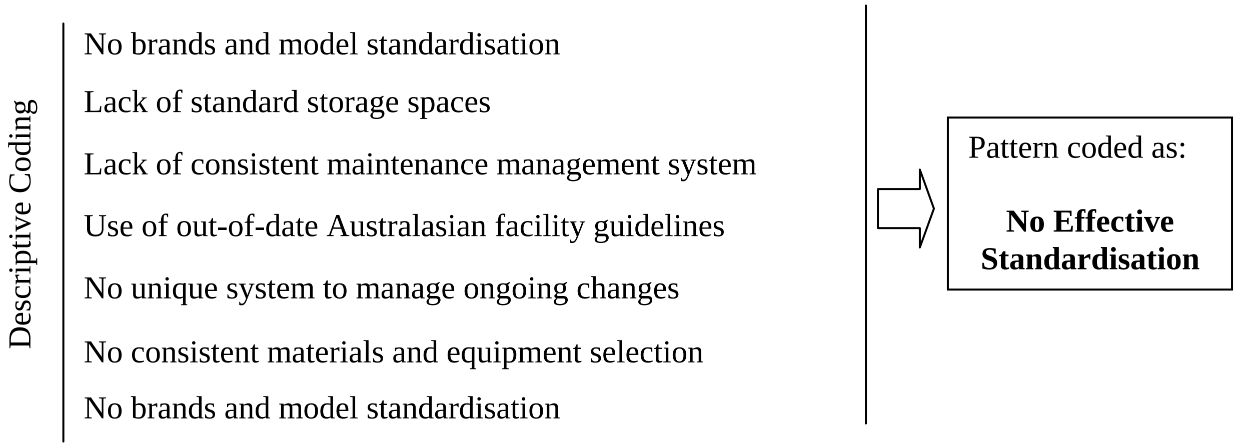


Figure 10. Example of assembly of problem codes to determine their pattern code

As another example, there were some passages of the texts that were initially coded as the current practices that were used to address the sets of problems. After researcher reflection using the pattern coding method, the final pattern code for different descriptive codes of the current practices was selected as shown in Figure 11. The next section starts elaboration of analysis of the collected data in detail.

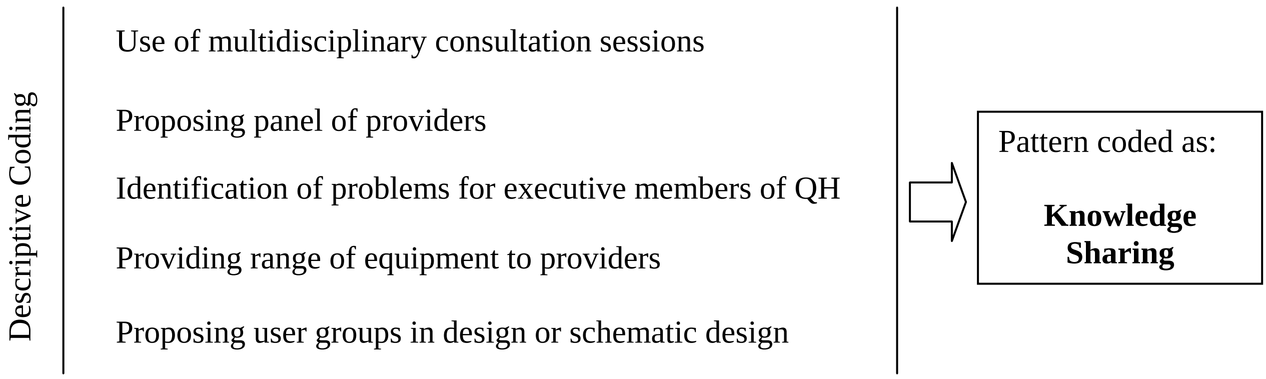


Figure 11. Example of assembly of current practice codes to determine their pattern code

A summary of the operationalising steps in the present research and the analyses adopted is presented in Figure 12.

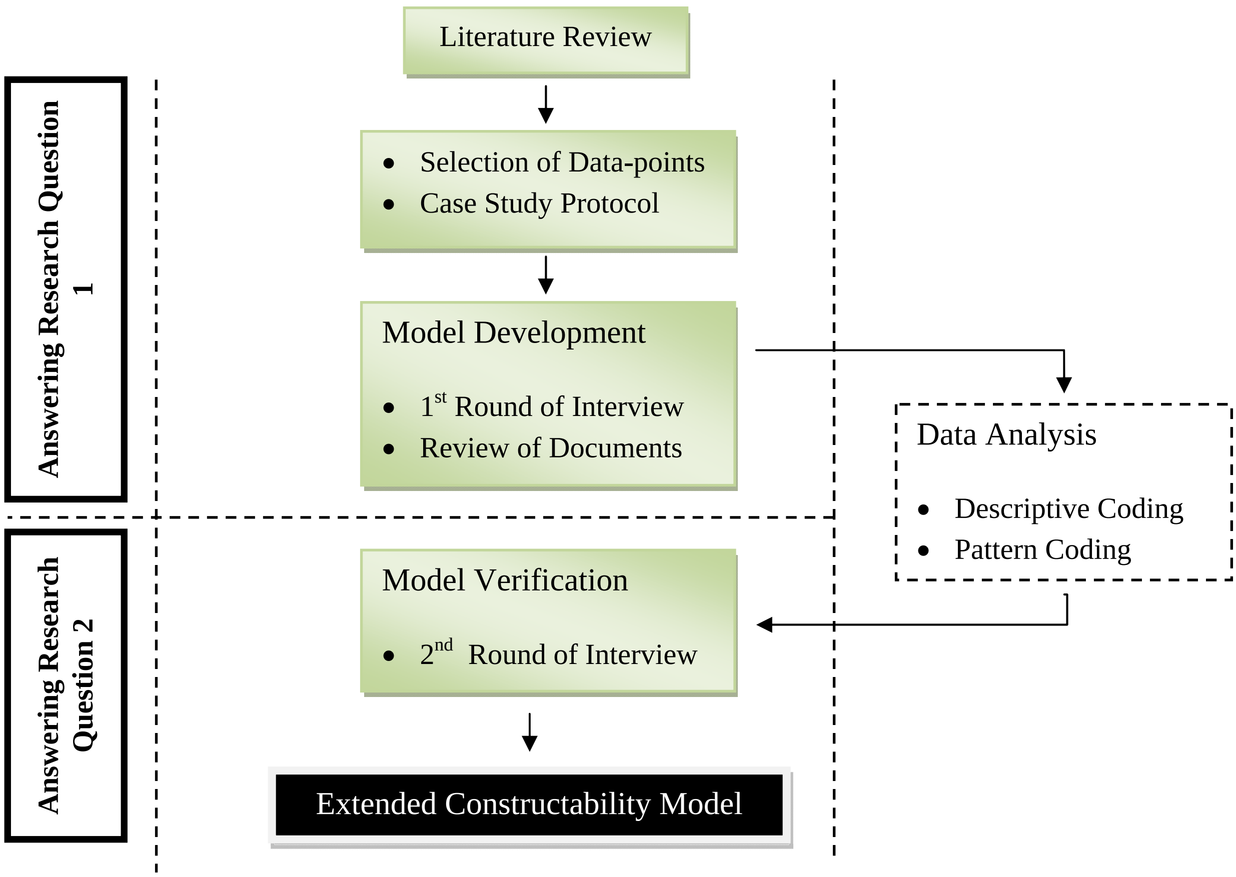


Figure 12. Operationalising steps in the research

Eisenhardt (2002) stated that a model development process should be completed through the three steps of: (1) sharpening the constructs, (2) verification of the relationships between variables, and (3) getting confirmation from the literature about the designed propositions. This research also formulated the propositions relating to the extended constructability model using the three steps.

Sharpening the constructs sets the validity of constructs through continuing comparison between the collected data to check if support can be constructed in a single proposition (Eisenhardt, 2002). This research used the same approach and compared different practices addressing the O&M concerns about health sector infrastructure projects, and formulated the operability and maintainability propositions for the successful delivery of infrastructure projects based on that.

Verification of the relationships between variables was the second step for development of the model in this study. Different practices implemented or suggested by the interview participants were listed, and the ways they helped the operability and maintainability implementation were tested. When practices are echoed by respondents, it enhances the validity and consistency of relationships (Eisenhardt, 2002).

Comparing the propositions with supporting literature is the third and final step recommended in the formulation of the principles. This comparison helps to define the generalisability of the study through an examination of the literature which conflicts with the propositions (Eisenhardt, 2002). This study has also supported the extended constructability principles with a review of the relevant literature.

However, some researchers (Sutrisna, 2009; Yin, 2009) believe that the quality tests for qualitative research are different from what Eisenhardt (2002) stated. The next section explains the different ideas given for the quality testing of qualitative studies and elaborates upon the quality factors considered for this research.

4.7 RESEARCH VALIDITY, CONSISTENCY AND GENERALISABILITY

Stenbacka (2001) argued that the evaluation of qualitative research through the use of the concepts of validity, reliability and generalisability is not convincing enough. For this reason, some researchers have suggested other methods for testing the interpretations and contexts of qualitative studies. For example, Auerbach and Silverstein (2003) suggested the concept of justifiability that covers the quantitative concepts of validity and reliability. Rudestam and Newton (2007) also suggested the concept of trustworthiness that justifies the concept of generalisability in qualitative research. Lincoln and Guba (1985) introduced the concepts of trust value, neutrality, consistency and applicability; and Yin (2009) highlighted construct validity, internal validity, external validity and reliability. As explained in this chapter, the selection of the method adopted in this study was influenced by the studies done by Eisenhardt (1989) and Yin (2003, 2009), so the concepts that they suggested for testing the quality of a qualitative case study were considered in this project. These concepts include validity, consistency and trustworthiness, and generalisability.

Validity

Sutrisna (2009) stated that validity in qualitative studies tests whether the research relationships really lead to the expected result; moreover, it checks if the research findings can be generalised to other project samples. To achieve this, the present study collected data from multiple sources (referred to as triangulation), aimed at understanding the reality, to ensure better integration of the research, and to achieve an expected level of validity, as supported by Yin (2003, 2009).

This study proposed two types of triangulation and both were at the data collection level, namely, (1) triangulation in a number of data-points, and (2) triangulation in a number of data collection methods, as suggested by Yin (2003). Firstly, it collected data from different data-points within QH. Secondly, it used a multiple method approach for the purpose of data collection, including interviews and a review of documents. This allowed the researcher to find a better perspective of what was really going on in the projects, resulting in better construct validity of the data.

Yin (2009) elaborated that to achieve a better internal validity to understand how and why an event leads to another, there is a significant need to carefully consider the type of analytical methods used. For this purpose, this study used different analytical methods like pattern matching and descriptive coding analyses to show how the target principles were designed.

Yin (2009) then elaborated on the concept of external validity, focusing on the generalisability of the findings. To achieve this, Yin (2009) suggested the use of replication logic, targeting the enhancement of analytical generalisation. This research replicated the findings through multiple health sector infrastructure projects within QH, satisfying the validity of relationships.

Consistency and Trustworthiness

Consistency and trustworthiness of qualitative research refers to the reliability of the results (Sutrisna, 2009; Yin, 2009); however, some conflicting ideas about this are evident in the literature. Sutrisna (2009), for example, stated that the rigour of the research design and selected methods fulfils the reliability concept in qualitative studies. Stenbacka (2001) believed that the use of the reliability concept in qualitative studies is problematic and is not convincing enough. In contrast, Yin (2009) and Eisenhardt (1989) believed in the need to enhance consistency and trustworthiness in qualitative analysis, which is considered the target case in this research project.

To ensure the consistency and trustworthiness of the data collected, the researcher prepared a case study protocol aiming to enhance the data collection process (see Appendix F). This resulted in the consistency of the data collected from different data-points.

Consistency in the data analysis process was another important issue considered in this research, regarding the way that the same coding process for the raw data was implemented, as examined further in the next chapter. Such a process results in reliability of the analysis and justifiability of interpretations (Auerback & Silverstein, 2003).

Yin (2009) also suggested keeping a main database for the case study. For this purpose, the transcriptions and documents in the present study were saved into a single NVivo file. All the documents were saved in separate files for each interviewed data-point in such a way that the raw data was always accessible.

Lastly, Eisenhardt (1989) suggested the use of similar questions for a pre-determined variety of participants in order to enhance reliability and consistency of the results taken. For the first round of interviews, this study targeted the top managerial staff of QH who had experience in operating and maintaining the health infrastructure projects and who were directly engaged in the O&M activities. For the second round, a wider range of participants, including other project stakeholders in addition to the O&M staff, were targeted, in order to help justify the reliability of the designed principles.

Generalisability

The generalisability, or "transferability" (Rudestam & Newton, 2007), of qualitative research is quite obvious as qualitative analyses are detailed enough for this purpose. Cavana et al. (2001) defined generalisability as the applicability of the results in one setting to others. Yin (2009) also confirmed that the whole aim of a qualitative case study research is to generalise a number of findings to a wider concept.

Different methods are given for testing the generalisability of case study research. Stenbacka (2001) suggested the wise selection of research respondents as a method for obtaining generalisability in qualitative studies; however, Cavana et al. (2001)

believed that the findings of every single project are only applicable to similar cases with the same settings. Eisenhardt (1989) suggested that a comparison of the designed emergent theory with the existing literature enhances the generalisability or transferability of the model built. This is precisely the approach that the present research project followed. As suggested by Eisenhardt (1989), this study reviewed both the confirming and conflicting literature to increase the generalisability of the concept designed. Such a comparison can also significantly enhance the external validity of findings (Yin, 2009).

4.8 SUMMARY

The main goal of this chapter was to clarify the research methodology chosen for this research project. The chapter began by explaining the interpretive paradigm as the philosophical position of this study. The research flow of this project was elaborated upon in relation to this paradigm. This included an explanation of the benefits and weaknesses of using an inductive theory building approach. The case study method was selected as the research method and Section 4.4 discussed the rationale for using this method and reasons for collecting the data from multiple data-points within the case study technique.

A description of the current research steps was then presented, including (1) preparation of the case study protocol, (2) selection of the data collection methods for model development, and (3) selection of the data collection methods for model verification. This included justifications for proposing first and second round of semi-structured interviews, and a document review process. The approaches and software used for the purpose of data analysis in this study were also explained, with a more detailed description of the coding processes given in the next chapter. A summary chart of the research methodology designed for this project was presented in Figure 9. This chapter concluded with an overview of the issues related to research quality and the different concepts on testing the quality of qualitative case study research projects to ensure that proper levels of validity, consistency and trustworthiness, and generalisability could be achieved in this study. Chapter 5 reports the data analysis carried out to identify the current O&M problems and practices in infrastructure projects, followed by a presentation in Chapter 6 of the data analysis implemented to identify the operability and maintainability principles.

Chapter 5: O&M Problems & Current Practices in Infrastructure Projects

5.1 INTRODUCTION

This chapter reports the findings from the interviews that were conducted in regard to QH infrastructure projects, and the data collected from QH guidelines and documents. The purpose of the initial part of the interviews was to explore the problems that O&M professionals were facing in their everyday practices. The purpose was also to categorise the practices that were regularly implemented to address these problems. The preliminary semi-structured interview questions were all organised around the following questions:

- What are the O&M problems of infrastructure projects?
- What are the current practices in addressing the O&M problems during the delivery phases of infrastructure projects?

Section 5.2 briefly describes the health infrastructure projects and corporate sections met during the interviews. It highlights some of the publically available information which justifies the reasons for their selection as respondents. It also includes a brief description of the data collection stage. In addition, this section elaborates on the type of coding method for data analysis and clarifies its use.

Section 5.2 discusses the problems affecting the O&M of health infrastructure projects, followed by the discussion in Section 5.3 regarding an initial categorisation of the current practices that were regularly implemented to address the problems. These categories of practices helped the researcher to construct the later interview questions which explored the possible ways to enhance the effectiveness and efficiency of operability and maintainability implementation within health infrastructure projects. Section 5.4 provides a summary of the findings in this chapter.

The aim of the discussion on this chapter is to provide a strong foundation for the further development of operability and maintainability principles in the next chapter.

It reports on the first round of interviews and the document review which, together, were the first step in exploring the current situation of O&M issues in Australian infrastructure projects. Figure 13 presents an overview of the research framework and shows how the remainder of the thesis addresses the research questions.

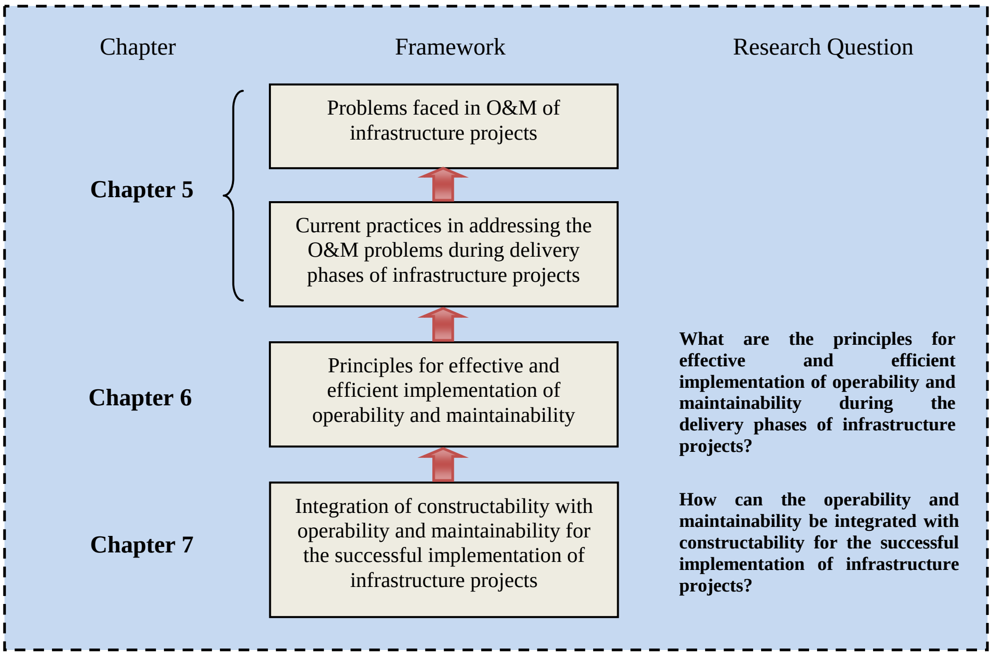


Figure 13. Reserach framework and focus of remaining chapters

The next section classifies the problems affecting the O&M of infrastructure projects, based on the collected data. It classifies the problems that O&M personnel indicated they were highly affected by.

5.2 PROBLEMS AFFECTING O&M OF INFRASTRUCTURE PROJECTS

The interview participants believed that health infrastructure projects were confronted with different sorts of problems over their life-cycle. These problems were more severe when it was a matter of O&M in multi-faceted infrastructure projects such as hospitals or laboratories. As reported in this section, the interviews yielded a number of findings on the O&M problems in current health projects within Queensland.

This section categorises the main groups of O&M problems, and then discusses the interview data that provided support for these findings. This grouping together with the responses taken from the respondents indicate that the respondents perceived the

O&M of health infrastructure projects as highly affected procedures in which preventive practices were essential. The different categories of problems highlighted by the respondents are presented in this section separately. The descriptive and pattern codings that were used to identify the problems affecting the O&M of infrastructure projects are presented in Appendix G. The problems are divided into the following twelve categories: lack of proper accessibility, lack of flexibility/adaptability, complexity, cleanability problems, safety issues, no effective standardisation, ineffective communication, poor knowledge, budget constraints, late or incomplete handover of documents, no preventive programs, and legislation and contracting defects. The findings related to each of the categories are discussed as follows:

Lack of Proper Accessibility

The interviews revealed that having easy accessibility to services and facilities was ideal for the respondents. During the interviews, the respondents often referred to their problems in regard to the lack of proper accessibility. One interviewee said:

> "It is more about accessibility issues. If it's done correctly, you can access that 24 hours without impacting others ... You cannot get access that much, because you don't want to be close to beds ..." [RBWH]

According to a manager in AMSU stated:

> "... that's [accessibility] not been considered as an issue.

However, there is a significant need to explore this issue deeply. It helps to provide alternative access paths for the O&M professionals in a way that does not disturb the medical treatment processes and fulfil the user expectations. It requires long discussions, resulting in suitable outcomes. A project manager shared:

> "Some issues like accessibility needs lots of discussions on how to improve it." [GCUH]

Lack of Flexibility/Adaptability

A health infrastructure project usually includes a group of different buildings with different specifications. New buildings need to adapt with older ones in order to prevent problems for the operational staff. A hospital maintenance manager said:

> "A lot of these hospitals are always a collection of new and old buildings. You see a link going across the road to another building. That is evidence of the system growing and adapting." [TH]

Characteristics of new and old buildings in infrastructure projects can be matched or can be very different from each other. Lack of adaptation with other buildings causes major problems for O&M staff. As some examples, a manager pointed out the lack of integration between current and older measurement units, and also between current and older fire alarm systems:

> "... when you are on a very old site with imperial measurements, then you have suddenly put a new building in that is metric, it does cause problems." [AMSU]

> "But the problem that creates maintenance issues is integrating that, so if you did an extension, is it integrating that? For instance, fire alarm systems. A lot of stuff now is digital as against 10-20 years ago, where most of them were analogue." [ASMU]

Other statements in the interviews showed that the fast technological advances of health facilities and equipment caused significant problems for the O&M staff. For example:

> "The problem is that what you could get 20-40-50 years ago no longer exist, so we're forced to get modern equipment. Where it becomes complex, and causes problems for them is that a lot of planning doesn't take that type of consideration in." [AMSU]

> "There was new radiological equipment that's coming on board in regards to MRIs, that type of staff ... We know that health care models are changing, that rapidly changes with the changes of technology." [AMSU]

> "Some new technologies, say clean steam or air con all come to old equipment, can't be done if you want to change from electric to gas pipe that they can be a significant issue and some maintenance requirements ... It evolves as the new equipment comes on the stage." [CHRISP]

> "The equipment get changed every 10 years and its requirements of the rooms, etc ... Medical industry usually has the largest changes." [RBWH]

Being flexible to new technologies was perceived to be an extremely important matter for the respondents. The respondents believed that there should be a high consideration of flexibility or functionality concepts during the planning and design stages. On this point, some respondents stated:

> "One of the things that I think that needs to be strong consideration in planning and design with point in mind is what I call flexibility." [AMSU]

> "... the main issue is a functional design and fit it for purpose, so it should be appropriate for the use of that specific space within that building,." [CDP]

> "... we work with CDP around the building and refurbishment of central sterilizing department to make sure that the equipment fit for purpose at the design ..." [CHRISP]

> "... fitting for purpose is an important issue for us. For that reason we as the QH, as the client, should have an approval authority." [GCUH]

To achieve such a flexible infrastructure, a project manager from HIDD admitted that being close to project users, builders and architects helped planners to build a product which was functional enough. The respondents cited a number of examples of existing inflexible/inadaptable facilities, indicating that there is a significant need for consideration of the flexibility/adaptability concept in the planning and design stages. Here are a few examples given:

> "We've had a number of facilities which had been built in probably operational for 5 years or so; and the things that we found were that they weren't built to accommodate the increasing growth in surgical services ... It is a real lack of flexibility of the designs." [CHRISP]

> "When facing with older masonry construction, those do not change, so that limits how you can modify, it limits flexibility." [RBWH]

> "The big issue on flexibility is on fired engineered constructions. Some buildings are fire engineered designed to save money at time of construction ... Now these buildings become a nightmare ... If later on you want to do something, modify a room, or put in some other materials that you are really obliged to go back to the original fire engineering design and report ... So it reduces the flexibility." [RBWH]

Complexity

The respondents believed that the maintenance of health infrastructure projects had become a very complex and expensive issue, and existing planning practices did not consider many operational issues. It caused them many difficulties, extra costs and as a result increased the complexities of delivering the right maintenance strategies. One informant noted:

> "Where it becomes complex, and causes problems for them is that a lot of planning doesn't take that type of consideration in. It doesn't try to standardise fixtures and fittings. It doesn't try to standardise the models, brands, types. It forgets all about that. That increases maintenance costs; it increases the complexity of delivering maintenance strategies." [AMSU]

Surprisingly, many compromises and optimisations were needed just after finishing the construction stage. The respondents said that they could not run this number of newly installed facilities with so many complexities, so they re-organised the costly training. They also lost a part of the liability period of the facilities, while most building contracts usually have a twelve month liability period only (CWMF, 2010). Here are a few examples:

> "In the year 2000, we got handed the main hospital building, it is 5000 square meters. Immediately it was handed over. I instituted a project to optimise the lighting. It costed 400,000 AUD and it saved 100,000 AUD in lighting energy-electricity." [RBWH]

> "We had a building. It was finished before Christmas. We haven't started using it yet [February], and we have been working on it since its hand over on December to get it ready for use." [TH]

> "The time that it opened, the staff had no idea what to do, so to bring the company back to do the training, they had to pay for it. So we've actually built quite a comprehensive training plan in the tender." [CHRISP]

In addition, two respondents from the RBWH shared that drawings and manuals were sometimes not of high enough standard which meant they were trying to use both manuals and training at the same time in order to prevent problems regarding the complexity of the manuals.

To succeed in the current competitive environment, it is important for hospital engineers to keep buildings updated in order to overcome existing complex issues. It saves the engineers from failing and lets the buildings continue servicing. A manager from AMSU stated that a building might have not been initially planned for a specific system when the building was built many years ago, so being updated made a lot of savings for them.

The findings also showed that having an effective and efficient design for healthcare projects is tricky, because healthcare infrastructure projects are extremely complex. Managers in two different hospitals believed the complexity of designs is more severe, as the total system is expected to work without interruption:

> "Hospitals are extremely complex buildings ... and so to get the design right you actually need to take the time and the right designers." [TH]

> "... when you put in such complexity to a system that the most important thing is it works, then you are going to introduce problems." [RBWH]

Having so many complexities in the design of project facilities also makes their maintenance procedures complex. If there are not enough quality tests prior to launching the operational phase of healthcare projects, the professional staff will face several problems in handling the units. This was noted by a manager as follows:

> "I have got the most complex emergency power system here ... I have had many problems with the consequences of making it work. It has been a nightmare! It's too complex. So basically introducing unproven, untested designs and technologies is an issue ... I think it is very important when you introduce a new technology or a new concept, they've been fully tested." [RBWH]

Cleanability Problems

It was reported that some maintenance managers within hospital projects were significantly concerned about cleanability problems. A respondent from RBWH believed that a very simple design should keep everything cleaned in such a way that building wastes cannot be seen going out through public areas. Another manager from GCUH said:

> "The cleaning I was talking about is about after 8 years time or 10 years time when we start to get dirty duct works ... It is very expensive and very easy to get wrong! If there is a leak anywhere, the whole things cause problems." [GCUH]

Carpets also seemed to be a critical problem in hospital projects. Wet areas need to be carpet-free in order to keep away bacteria and infections, specially because some bacteria are antibiotic resistant. This problem was raised in the following statements.

> "10 or 15 years ago we began to put carpets on hospital floors. Long time ago we never put carpet because there is always lickings, etc. Now we are coming back to it. Carpets increase the infections! It has severe incredible biological issues and offcourse nowadays we know 3 or 4 types of bacteria which are now in the carpets and they are antibiotic resistant! So they are much harder to remove!" [TH]

> "... that happens [dirt and infections] where they want to put carpets in clinical areas. We've provided advices on where we think things should go." [CHRISP]

Keeping the areas hygienically and biologically clean imposed many changes to old health project environments and equipment, resulting in extra costs. A manager in the HIDD believed that the problems were not just because of incorrect design mechanisms; they were more about having the right equipment and environments. In addition, a maintenance manager from TH highlighted the need to have a higher level of infection control standards in order to be much sharper in managing the problems.

Safety Issues

A maintenance manager from TH stated that new safety instructions were sometimes making extra work for O&M staff. He highlighted this example:

> "We've had to fire-rate the building that wasn't a requirement when it was built, so there have been a lot of fire doors and walls, smoke doors and walls. The fire alarm system had to be replaced. It had no evacuation system, so that's got to head to install." [TH]

Moreover, those safety constraints that limited O&M staff from their daily jobs caused delays to maintenance procedures. A manager from the GCUH project explained this example:

> "In our mental health building I would like to have maintenance access ... A switch board is located for each area. Mental health patients might harm themselves with those switch boards, so we don't put them up in the plant room. It's more difficult to get to, harder to maintain, but clinical needs here are greater than maintenance needs." [GCUH]

Although these two examples seemed to be unpreventable, the establishment of a consistent policy preventing the changing instructions and constraints could make a big difference, as suggested by the TH and GCUH managers.

Carpets were not only dangerous biologically; they could also cause severe harm to hospital staff. Pushing trolleys on carpets is much harder than pushing them on soft carpet-free floors. A maintenance manager commented that QH had been sued many times for lacking a fully safe work environment:

> "It was the carpet time, so we put carpets everywhere. Staff took lower back injuries over time [2-3 years time], and it was a design error. We lost lot of money people sued us for it for not having a right work environment." [TH]

Environmental issues are at the centre of attention for the Australian construction industry and the type of materials used in healthcare projects is always supposed to be safe. A manager from the RBWH highlighted asbestos as an example of a dangerous material that hospital projects used to use in the old days, but which is now banned according to new building code regulations. Removal of this dangerous material imposed extra work on the engineering departments of health projects. The RBWH manager said:

> "Asbestos has been banned here for many years. There are some buildings that used to have asbestos. The policy on this site is when you go to work on a building that has asbestos; we have it removed first." [RBWH]

No Effective Standardisation

The maintenance cost of infrastructure has increased not only because of the improper selection of quality materials and equipment (as emphasised by respondents from the TH and GCUH), but also as the result of using them much longer than their designated life span. In addition, the growth of the aging population has increased the need for more spaces, and infrastructure managers are usually expected to create new spaces out of current spaces. Lack of a consistent standard that could effectively fix the settings was an important problem for O&M staff, as repeatedly highlighted by different respondents from the CDP, CHRISP, HIDD, RBWH and TH. Some examples are highlighted as follows:

> "A lot of our infrastructure goes a lot longer. We've got assets that are 50-60-70-100 years old. This stuff is still in use, so the life cost if you get beyond 30 years increases a lot more, because we are holding the stuff a lot more." [AMSU]

> "Everybody is crying for storage space ... This is something they cut, cut, cut, and cut in the planning and design stage!" [RBWH]

> "Probably the biggest single complaint you would find in any hospital building is 'not enough storage'. They never build enough storage and enough right kind of storage ..." [TH]

A manager from the AMSU also stated that there was no attempt to standardise models, brands and types in the operation of health infrastructure projects, and he thinks this has been a big mistake.

In addition to that, managers from the HIDD and CHRISP asked why there should not be a unique maintenance management system for every single health project in Australia. They believed that many of their problems in the O&M stages were as the result of using out-of-date Australian guidelines, because there were many gaps in these documents. Some respondents from the CDP and RBWH also argued that such a lack of effective standardisation at the operational level made it a big challenge for them to adapt themselves to ongoing changes in health equipment.

Inefficient Communication

Analysis of the interviews shows that improper communications did not only take place in the planning and design phases, but they also occurred in the construction and post-construction phases. There was evidence of unclear decision-making as the result of communicating with the wrong people. Here are a few examples:

> "It is all because of employing people who are not appropriate. All their things are savings, budget. So they approve this cheaper thing and they are there for the project, and the operational and maintenance people got to live with it for career." [RBWH]

> "The people who actually design the hospital were two incredibly experienced nurses ... Did they spend enough time with the engineering and maintenance? They didn't! Those days, they didn't even recognise the necessity for an engineer ... I've seen much more disastrous outcomes." [TH]

A maintenance manager from TH also believed that conflicting opinions during the design resulted in ineffective communications, causing later operational problems. He argued that these conflicting opinions could also imply some mental frames for multi-stakeholders' consultation sessions. Another manager from the HIDD explained that engineers still needed to learn how to communicate efficiently in the planning stage.

In addition to the highlighted poor communication practices in the planning and design stages, there was also evidence showing that this disconnection between different project stakeholders still existed at the operational level.

> "Sometimes I think there is a disconnection between engineering and the clinical areas."[CHRISP]

> "Normally in projects they do try to consult with people, but as you now sometimes it is because it is in contract to consult, not a true consultation process!" [RBWH]

Two managers from the CHRISP and GCUH believed that this disconnection might be because of the poor communication skills of maintenance contractors. They thought that no-one should expect them to be able to communicate with others in the same was as the nurses or doctors communicated. Other managers from the HIDD and TH admitted that maintenance contractors cannot argue as well as clinicians, because they do not have enough verbal skills to get their opinions across.

One of the maintenance managers at the RBWH stated that the situation gets worse when the O&M staff need to work in a hospital environment, because working for sick people is not really easy. He claimed that it is harder to communicate with sick people because they have higher expectations which might cause some problems during communications. He described this issue as a user-related defect.

Poor Knowledge

Analysis of the data indicated that poor knowledge could be in three different types: firstly, it could be a lack of technical information; secondly, it could be political or legal issues that led to poor knowledge; and thirdly, there could be social or cultural reasons that led to weak knowledge.

An interviewee from the RBWH argued that poor training and manuals caused operational staff to have weak technical knowledge about equipment and services, resulting in poor implementation of maintenance practices. He also stated that there were not many people who were experienced and knowledgeable enough. Similarly, a maintenance manager from TH said:

> "Most often times, to get an engineer or to get someone who really has maintenance type of background is not just necessarily easy." [TH]

Another manager stated:

> "I think we used to have a number of really good engineers that understood, specially with some of the specialist services, and we've lost that across the stage." [CHRISP]

The second type of poor knowledge highlighted by the respondents was knowledge caused by political or legal reasons. The respondents believed that political and legal issues negatively influenced the O&M of infrastructure projects. A manager described it as follows:

> "... It's like a dog chasing its tails. You got a weak start and then forever you try to compromise from there." [RBWH]

Fast political changes and early governmental announcements with nil or minimum planning were among those obvious political reasons for poor knowledge. Some comments related to this point were as follows:

> "... one of the challenges we had is that we are responsible for many projects in Queensland and for all those projects there has been nil or minimum planning behind those announcements." [CDP]

> "There just isn't enough money to be able to do what they want to do, so they need to do something and that comes from a political promise..." [CHRISP]

> "... that's the political process that we live under and we've got to be prepared to necessarily to accept it ..." [HIDD]

Another political problem highlighted by a maintenance manager in TH was that some QH corporate section staff did not have relevant maintenance experience. He believed they might have been good in securing money and managing contracts, but were not effective enough for maintenance purposes. This created many wrong political policies that were usually made by bureaucrats who did not know anything about the O&M procedures. An informant from the RBWH stated:

> "... That's bureaucrats who handle the negotiations and the contracting. Then they employ consultants, and then they got the budget ... They are not from engineering or construction people, but they are powerful people." [RBWH]

The third type of weak knowledge mentioned by the respondents was weak knowledge caused by cultural or social reasons. A manager from the HIDD stated that QH has always focused on building aspects, rather than maintenance. In other words, maintenance was not considered to be as essential as other project phases:

> "... when I was first got to the hospital I found that the major issue is the attitude of the business to maintenance not as mandatory, but as discretion area. So maintenance was discretion area expenditure, not a mandatory." [HIDD]

Two respondents highlighted different examples that showed the lack of awareness of project designers regarding social changes of society. They concluded that this lack of awareness resulted in different operational problems in current health projects. They said:

“People are getting fatter and fatter. Sometimes they are 300 kg or 200 kg. These people visit hospital more often than others. Our children are getting bigger and bigger, so all those things have a hospital consequence ... so we also need better and larger trolleys, larger places, etc.” [TH]

“The fact is that we have an increasing asset base in QH ... growth of population, aging population, and many other things, so the cost of maintenance will increase.” [AMSU]

A maintenance manager from TH stated that clinicians usually did not have any building understanding. Maintenance staff also did not have enough knowledge about changing clinical needs and clinical roles. Such lack of mutual knowledge limited the ability to predict needs and caused major problems for the operational staff.

Budget Constraints

Comments from some respondents within the QH corporate section revealed that it was hard for them to find O&M professionals to make an input into the planning stage. This view was shared by two managers:

“... that might suggest that there are a lot of people could give input to how a pathology lab could be designed, but you can’t get people offline ...” [HIDD]

“I think what happens is that it’s mainly the reason that engineering isn’t actually a part of user group.” [CHRISP]

In addition, there were not often enough incentives and interests for O&M stakeholders to join the planning stage and make their inputs. A manager from CHRISP said they had proposed many evaluation teams for infrastructure projects, but the O&M staff were usually reluctant to join. In response, a maintenance manager from the RBWH believed that there should be a profit for contractors, but they had had no long-term interest in these sessions. Two other maintenance managers from the TH and GCUH echoed that they usually did not have enough time to participate in the planning stage consultation sessions. They commented:

“... the real life situation is most often we don’t have enough time to be involved [in user group sessions], as fully as we need to be.” [TH]

"Probably the biggest thing is time." [GCUH]

It was also reported that the planning phase gets more expensive when a number of O&M professionals enter into it to make inputs. The respondents believed that planners and maintenance staff were two groups with two undoubtedly different interests. They thought there was a significant need to optimise their involvement and decision-making authority. For example, a manager noted:

"... when they open their mouth and say it must be done like this, it costs money. That is why a lot of times; they avoid having their operation and maintenance people ... Maintenance perspective is life cycle. This one [planner] is upfront cost. That is the problem. When you have 2 bodies with different interests, it's very hard to meet." [RBWH]

Low budget was one of the biggest issues for the respondents. Some of the respondents from the QH corporate section said:

"There some times that the funding does not meet the project needs of the building ... There are extensive preventative maintenance programs that need to happen across a number of areas, but the funding is not enough to be given to do that." [CHRISP]

"I think generally that maintenance is always underfunded in health ..." [HIDD]

Some other respondents from the QH district section blamed underestimations and money constraints as the main barriers to the proper implementation of their works. Evidence of this was apparent in the following comments:

"At X hospital, there wasn't much money to do much works to do what we wanted on that site. We had budget constraints." [GCUH]

"Hospital construction is very expensive; space is very expensive. So when I face users' expectation, I don't go to solve it as a maintenance manager; I go there as a magician!!!" [RBWH]

"They always underestimate the costs particularly the cost of design, and therefore if you are not paying a full design fee your consultant is not going to put fair a bit of effort ... When the project needs more money and they

> don’t have it, they just try to finish it with their lower budget ... you start leaving parts of the design out ... which produces incorrect functionality of the building and pity use of building.” [TH]

A project manager from the GCUH commented that the low QH budget was always because of unsustainable market conditions. He argued that QH was always changing and it usually took longer for other departments to understand the new system and work with it. These ongoing changes resulted in continuing changes to maintenance procedures. On this point, two managers said:

> ‘... if you look at a building site now there are many emails asking for going back or forward getting anything fixed.” [TH]

> “We construct this, and I say what do you know about hospital? What do you know about interaction of this building on the other buildings if we don’t know what is going on!” [HIDD]

Changing maintenance procedures affect other ongoing services that might become a conflict and cause disputes with clinicians. One project manager said:

> “It’s usually a project team who just ring up with a query about, you know ... the architects want to do this, but the clinical staff are saying this, what do you think? ...’” [CHRISP]

> “I suppose that when we come to conclusion, it is very difficult to have the medium, to meet the clinical needs, meet construction needs, meet budget, and I suppose meet some time frames.” [GCUH]

Late or Incomplete Handover of Documents

Maintenance issues are usually considered very late in projects. Most of the respondents agreed on this point. A manager from the AMSU said:

> “The opinion is the engineering and maintenance sort of things are largely the last issue that is considered ... The point I am getting to at the moment is all seems to be secondary.” [AMSU]

Many believed it was because of incomplete or low quality delivery of construction documents. A maintenance manager at the GCUH described the final construction documents as rubbish. Another maintenance manager at the RBWH said that health projects were usually handed over poorly. He gave the example of a new security system that had been set a few months previously, but for which the maintenance staff had not been given any manuals. A manager within the HIDD also commented about this issue:

> "What which is difficult and not enforced is the timely availability of operation manuals and that sort of things, and they would come later and the argument would be it's ok you don't need them yet, because you are within defects liability period." [HIDD]

No Preventive Programs

A manager in CHRISP stated that having early programming could significantly help their team to manage different maintenance practices. It might be necessary to spend some funds for these preliminary programs, but it could save a lot later on. He said:

> "There are extensive preventative maintenance programs that need to happen across a number of areas and a number of things, but the funding is not enough to be given to do that." [CHRISP]

Another manager from the HIDD claimed that the maintenance stage usually lacked enough human resources as a result of wrong programming and underestimations. A maintenance manager from TH believed that incorrect programming occurred because some designers did not have enough hospital experience, so the designs were not necessarily compatible with real building uses. He also highlighted the incorrect selection of materials as another result:

> "So you are managing some of those construction hangovers with inappropriate materials which were fine those days when they were built, but not now." [TH]

Legislation and Contracting Defects

There was significant evidence showing that O&M staff needed to spend plenty of time handling disputes, as a result of changing legislation. It usually took most of their energy and imposed extra costs. It was often necessary to recall and deal with those contractors who should make a change on a specific part of a project, yet the contractors may not have the same staff anymore. Architects were always considering many authentic issues, but they never came back to see how O&M staff were struggling with their designs. Some informants said:

> "It is very energy and time wasting, you write a lot of memos, you provide a lot of evidence, and you then fight with people!" [RBWH]

> "The original contractor who built it, he has lost the staff that did it then and he doesn't have staff now that are capable of doing things to the system ..." [RBWH]

> "We've had a number of projects, people; specially the architects think they know what's needed. You know they built hospitals before, so they know, but they don't actually get back and see what's left!" [CHRISP]

Similarly, the evidence showed that healthcare projects have always suffered from underestimated decisions made by politicians. Unrealistic assessments by inexperienced people and changing legislation caused low quality implementation of different maintenance strategies in health infrastructure projects, and as a result major O&M extra works were needed. Many disputes were reported over unrealistic political decisions. Two managers commented:

> "There just isn't enough money to be able to do what they want to do, so they need to do something and that comes from a political promise." [CHRISP]

> "... we start to get approval by saying hey we cannot deliver it by end of 2012, it can be done by 2013. You said you want this within this budget, it is not feasible! And then to get approval, but quite often there is political pressure ... It is difficult to deliver what is fully required and of course each district want more done, and you know we are here to deliver government policy ..." [CDP]

In addition to the changing legislation, the type of contract signed for the construction of a health project could significantly affect the ways that O&M staff were involved in the early PLC phases. A maintenance manager in TH believed that the type of contract could directly influence how O&M considerations were involved and what difficulties O&M staff faced throughout the post-construction stages. This could prevent any chance for project builders to go through the variation process and cause difficulties for O&M staff. He said:

> "... the contract that they have signed is based on a specific design. If the designer has got it wrong, then the builder can make money through the variation process ... so if the maintenance department want something to be changed to make it easier to maintain, builders will generally do that provided it doesn't cost money." [TH]

An interviewee gave an example of how a public-private partnership (PPP) contract can negatively influence the involvement of O&M personnel in the planning phase of infrastructure projects, as follows:

> "So with that PPP, they have property issues and therefore I can't go through one of the meetings! How stupid is that? Later on when it gets to the preferred supplier and he starts working on the preferred contractor, then we will get involved in the drawings, but at the early stage the decisions are going to be made that we don't know!" [HIDD]

Two other respondents explained how using a managing contractor helped in finding people who caused the faults; however, it made profit the only motivator of the builders, as follows:

> "The old building method was the builder built what QH has told them ... They use the consults to make sure it applies the BCA and standards, but if the builder got it wrong and was documented that way which is QH fault; it was always QH problem. The managing contractors are a different story. They make the schematic design, the design development, and all the issues before construction like drawings and getting approval ... If they can't prove it's their issue, they will consult. So the process is changed and now it is their responsibility to get it right, because they are the managing contractor." [GCUH]

> "... there has been an evolution from the initial architect control, fully documented form of projects, and then they are designed and constructed where basically that contractor has almost full control ... That evolves to decide whether to use managing contractor. Where we use of this sort of contract, the motivator for the builder is always profit ... and when my

> motivator is profit, then quality, long-term issues, sustainability and all these holistic considerations will suffer. You know, they will be compromised." [RBWH]

The findings reported in this section show that O&M stakeholders faced diverse sorts of problems when they were operating and maintaining health projects. Some practices to resolve these problems were highlighted by different respondents from both the district and corporate sections of QH. The next section focuses on these practices and their categories.

5.3 CURRENT PRACTICES IN ADDRESSING O&M PROBLEMS

The preceding section highlighted the problems occurring in the O&M of health infrastructure projects in Queensland. These O&M problems suggest the need for project owners to review their current practices to find out new ways for more effective and efficient delivery of infrastructure projects. According to the Capital Infrastructure Minimum Requirements (2012e), "the cost of building assets over their life cycle is many times greater than the capital cost of construction". As a result, all PLC phases should be considered with the same weight.

The interviews showed that the respondents performed different practices to address the O&M problems. This section reports the findings on the practices that O&M professionals implemented to face O&M problems. In order to refine the current practices to enhance operability and maintainability implementation, some QH documents and guidelines were reviewed, and those findings were also used to support the evidence of the existing practices.

The step reported in this section made a significant contribution to this project, because it categorised the different practices that implied valuable principles for more effective and efficient implementation of operability and maintainability concepts. The different categories of current practices highlighted by the respondents are presented in this section separately. The descriptive and pattern coding techniques that were used to come up with the current practices in addressing O&M problems in health infrastructure projects are presented in Appendix H. These practices included early programming, standardisation, knowledge sharing, integration of knowledge, control of handover stage, strengthening communication, developing knowledge and experience, regular monitoring, controlling project costs and lastly safety considerations.

Early Programming

Decisions that are made within the planning phase can have significant influences on the overall project objectives. The case data revealed that there were many early practices that O&M stakeholders implemented within the planning stage to prevent O&M problems. It actually shows that QH was aware of the importance of making early decisions in infrastructure projects. Early programming was one of the early practices implemented through capacity study, planning prioritisation and involvement of the procurement team in the selection of builders.

Analysis brought to light that the capacity study was one of the major actions implemented by managers in the corporate section of QH. A manager within CHRISP elaborated that health projects consist of very complicated equipment, medical devices, different machineries and services working in each area, so there should be a background study to check what will exactly be going on in every single building and room. He stated that participation of O&M staff in capacity study review sessions helped the project team to design for the right purpose. He said:

> "We do capacity study ... we measure the amount of instruments or medical devices that have to be reprocessed and the time it takes to do that; and then we look at the surgical services that they provided that time and then we take that data and scale it up with what the projected surgical services are going to be. So then we calculate how much machinery we need ..." [CHRISP]

Analysis also revealed that there was a number of continuing early programming practices toward planning prioritisation. Early and inappropriate planning done by politicians made it very hard for the project team to deliver what was really required. Prioritisation of needs and necessities for the project was therefore an ongoing practice for the corporate section of QH; however, planning prioritisation was just a temporary treatment for wrong political decisions. A manager elaborated on this as follows:

> "... quite often there is political pressure ... sometimes we can get changes to the approval specifications ... it is difficult to deliver what is fully required and offcourse each district want more done, and you know we are here to

> deliver government policy, but it has always been an ongoing negotiations to say what we really need to do to ensure that everything is going to operate well and it's putting up together for additional money. It is an ongoing challenge, it is prioritisation." [CHRISP]

Having a procurement team results in value for money through the supply of goods and services with the lowest cost and proper allocation of risks (CWMF, 2008a). An interviewee from CHRISP also reported that a procurement team was involved in direct contact with CDP staff and its main responsibility was to select the right builders for the project. They were aware of every single action in the planning stage. He noted that:

> "We have actually added a category, so that the builder procures, but QH selects which makes it a little bit better. And we've got a procurement team that follows all of these projects, and that procurement team is across what's happened, so they know the issues; they are in consultation with the capital delivery program and those sorts of things." [CHRISP]

Standardisation

The need for the standardisation of practices, systems, management techniques and software was echoed by different respondents many times. Many respondents believed that the use of mandatory master planning and proposing different workshops within the AMSU helped to prevent many O&M problems. Some evidence also showed that having a standard business solution design was helpful. In addition, use of OMTRAK software during the construction phase, followed by a streamlined instruments management system and a computerised maintenance management system during the post-construction stages, was very supportive for better identification and improvement of the problems.

There was evidence showing that a review of the master plan or service plan helped to prevent many upcoming O&M problems in health projects. Different techniques were practised by project professionals. For example, a manager from AMSU highlighted that user group sessions/multi-disciplinary consultation sessions were proposed by the AMSU which were well supported by QH. The AMSU had made a lot of effort to propose these sessions in a standard and timely matter; however, a maintenance manager from TH believed that there were some mental frames in these sessions. He stated:

> "You would always have what we call it multi stakeholders consultation process, and that's what QH does it very well ... I've been in many processes like this in QH and getting the right ideas to the solution is an incredibly important thing, but the mental frame to overcome is to ask the people who actually do the ground works ... I have never sat in a meeting where these people have not contributed with a lot of very good points." [TH]

A manager from the AMSU continued that they had also proposed different workshops that O&M professionals were also a part of as well as the project designers. They reviewed the final planning documentations and shared their views to finalise the plans. A manager from CHRISP also stated:

> "Many maintenance people have been involved via workshops, and also by reviewing final documentations, but also were sent out to some external industry experts as well for them to review it ... we sit them as the key part of tender for the planning and design phase and even the construction. They will be the key person around the table and the design team work with them." [CHRISP]

The design of a business solution plan as the target standard through reviewing the master or service plan was then implemented in health infrastructure projects. This plan was designed as part of the practices provided by the AMSU and the whole policy was made by the CDP. An informant from CHRISP noted:

> "We have a policy that actually mandates people have to consult with us, and that policy was developed by CDP. They can start consulting with us before starting the project or as part of when they know that there is a project that's going to happen, even before planning as part of master planning or service planning. So now we are involved as reviewer of service planning and master planning. We actually build a business solution design ..." [CHRISP]

Apart from highlighted standardisation practices implemented within the planning and design phases, a manager at the GCUH recommended the use of OMTRAK software as standard software to help tracking construction works. He stated that it considerably helped both contractors and the management team to stay up-to-date. He said:

> "What we are doing here, it is a piece of software that managing contractor goes and purchases it ... They didn't have to, but they decided to minimise the risks to them. You format the software in a way that people are forced to write information in the right format. This software is under quality control of the consultants and it can be seen by the managing contractor." [GCUH]

The data showed that in addition to using standard software for the construction phase, the respondents also used different computerised maintenance management systems in their projects. A maintenance manager at the GCUH commented that a lot of health projects put it in the contract that providing a computerised maintenance system is a must. Another respondent highlighted an example of this as follows:

> "I know Ipswich hospital as an example bought its own BEIMS [Building Engineering Information Management System], and there is range of those in market. So the larger hospitals had a range of these things like MEX, BIEMS, MIM." [HIDD]

It was reported that besides having a computerised maintenance management system, instrument management systems were also used in order to specify where each instrument or equipment should be placed at any particular time. It prevented maintenance staff from having to spend too much time searching for the instruments or equipment. A manager from the HIDD highlighted the need for a standard instrument management system as follows:

> "... we are looking at, as part of that automation, instruments management systems. They are going to integrate with machinery, so we can be able to collect data out of the machinery, but also be able to tell people where that instrument set is in the bad point in time, so people don't have to go searching and that sort of thing ... No more over stocking unit! Everything had a place!" [CHRISP]

Knowledge Sharing

The interview data indicated that most of the respondents believed in knowledge sharing as an effective approach to prevent many O&M problems. They highlighted that they had already brought O&M knowledge into the planning and design phases using different techniques, including the identification of O&M problems to executive members of QH, proposing a panel of providers or multi-disciplinary consultation sessions in the planning stage, and organising user group sessions within the design or detailed design phases.

To deal with inappropriate decisions made by politicians, engineers needed to lobby with the people who are normally in contact with them. The AMSU has always played this role in QH and it was a very usual practice for QH professionals to be in contact with the AMSU office to clarify their O&M needs to the executive members of QH. This was highlighted by a manager in CHRISP as follows:

> "There is a group in the QH that is asset management services unit and from our perspective we identify the problem and we took the problem to the executive of the QH ... AMSU people are those who can at least make lobby on behalf of the engineering ..." [CHRISP]

A manager from CHRISP stated that proposing a panel of providers and multi-disciplinary consultation sessions in the planning stage also helped to anticipate the volume of the required services and equipment in health projects. She even believed that the predictions of facilities and operational needs through these sessions were much faster and more effective that reviewing service plans. A maintenance manager from TH noted that these consultation sessions would be successful if there was no mental frame in it.

The analysis shows that sharing O&M knowledge was not limited to the planning phase only. The respondents participated in some user group sessions in the design or schematic design stages to bring their operational needs upfront too. This helped them to provide the range of medical equipment to the designers which facilitated a fit for purpose design. Evidence on this point was given by the respondents as follows:

> "We had engineering user groups to look at whole building services issues ... The purpose of that is to use their experience to save the design issues." [GCUH]

"... when we go to designs, when we are developing our functional designs, briefs, and detailed designs. We are close both with the users and architects and builders to help planners to build a product which is functional ... We had more meetings there if there was any need to do changes as a user group session." [HIDD]

"We just give the range of equipment that possibly is there. So they will do a number of different holes going down into the plumbing, so those alternatives can be used later on." [CHRISP]

Integration of Knowledge

Prior to the recent development of technical guidelines for design of health infrastructure projects in QH, most designs were based on a guideline named the Technical Series (TS11) which was compatible with New South Wales (NSW) infrastructure projects; however, the interviews showed that it had always been an important aim for QH to update the technical guidelines based on the Queensland standards, legislation and local specifications. An informant stated:

"Prior to this we used to refer all our design team to use document produced by NSW health department called TS11 and that was a technical standard. That was also designed by external consultancy too. We were using it but we really needed to update those, adapt that for Queensland to use Queensland standards and legislations." [CDP]

This was where the initial thinking about the integration of O&M knowledge into the delivery phases of PLC was raised. An interviewee from the CDP stated that QH had made many attempts to bring the right people into the design phase. The evidence showed that to get the right business solution design, specially in larger health projects, the Building Information Modelling (BIM) process was used to clarify the needs of project facility components to project designers, targeting a more functional design. An informant said:

"Some bigger projects are now using BIM which also comes with facility management component and those are assisting with the handover of documents and O&M of the buildings. Some of the bigger hospital projects are doing that like GCUH." [CDP]

Control of Handover Stage

Current practices implemented during the construction stage of health projects indicated the awareness of QH about controlling the installation quality of services and facilities and the handover process. The interviews showed that having an experienced maintenance manager with enough authority during the construction stage could result in regular checkups and quality control tests. The allowance to do such regular testings should be made within the design phase (CIMR, 2012j; SAMF, 2010d). Two maintenance managers highlighted an example and shared the influence of such comprehensive supervision as follows:

> "Regular quality control and regular inspections can prove to asset that that duct will be cleaned when that project is finished or it might need a special type of clean." [GCUH]

> "If you do a body of work and then have to test it yourself, you're going to make mistakes, and you won't pick up those mistakes. An independent set of eyes can find them. It is something that is getting proposed in GCUH." [TH]

In addition, the analysis provided evidence for post-construction final checkups within infrastructure projects, ensuring that the project was built functional enough. This was necessary to ensure that clinicians and maintenance staff could start operating and maintaining the services and facilities with no trouble. A manager noted:

> "We've been doing some works there to prove that and to ensure that health service people are ready to accept it and are comfortable to accept that building at the end of construction period and they are comfortable that the building is functional and ready for use." [CDP]

Strengthening Communications

To overcome weak communications, the respondents believed that having a maintenance unit at the construction site facilitated easier involvement in the construction management team's decisions. Moreover, it assisted in creating the opportunity for more interactions with the builders. All these strategies could help to save more in the O&M stages through the prevention of problems that could otherwise occur.

The analysis shows that infrastructure projects currently under construction within Queensland have recently employed experienced maintenance professionals to assist in the construction stage. This gave them the chance to have a positive influence on the project management office's decisions. A manager commented:

> "Generally we, by getting involved upfront with the building, construction, etc and with the management decisions, we can affect on that a little bit. If it is considered essential to the maintenance, we jump up and down until it gets done!" [RBWH]

The GCUH was among the projects that had a maintenance office on site while it was being constructed. A project manager having a professional maintenance background was fully employed to make inputs into the construction process. This manager shared:

> "Just out here we are having building maintenance units. They travel around the buildings ... When we firstly suggest having a building maintenance unit in a construction site; they said no you're not going to have it! We developed the case and prove that it is cost effective and necessary ... I think someone like me should have been there to make sure that mistake didn't happen." [GCUH]

Being present at the construction stage gave maintenance professionals the chance to interact with the builders. This helped the O&M staff to pass all the necessary information to the builders, ensuring it was easy for engineering staff to operate and maintain the constructed services or facilities. A manager commented:

> "Initially it was only planners and designers, now we are actually in construction stage. We have a very high level of interaction with builders ... We can sort of pass all the information to X [current onsite maintenance manager] about what's required to run. It's all up to X to make sure that from his perspective that it is easy for engineering to maintain and provide that service ..." [HIDD]

The interviews showed that QH was aware of the need to use builders that do their work under warranty. The O&M personnel had plenty of difficulties when tracing builders to come back and fix the problems. For this reason, QH decided to focus on contractors that can provide a warranty for their work. A manager said:

> "... we only utilise the contractors under warranty conditions for many years." [RBWH]

Developing Knowledge and Experience

The collected data shows that some practices were implemented during the post-construction stage to develop the O&M knowledge of staff. Despite being late to make structural changes for better operability and maintainability implementation, the respondents pointed out that proposing extra training for O&M personnel, while they were given the manuals earlier, was effective.

A maintenance manager noted that organising extra training for O&M staff was a solution to make them familiar enough with the installed services and facilities in the buildings. The analysis revealed that health projects often paid too much to train their staff, but there was evidence showing that the amount of training was not still enough. A manager noted:

> "It is very important that they get appropriate training for all these different systems that are put in the building we are in. Sometimes there has been some issues on that the training was not sufficient." [RBWH]

One manager also highlighted that based on new regulations, a complete training plan should be in the tender to prevent future O&M problems and costs. He said:

> "The time that it [this project] opened, the staff had no idea what to do, so to bring the company back to do the training, they had to pay for it. So we've actually built quite a comprehensive training plan in the tender." [CHRISP]

The interviews showed that recent QH projects paid more attention to the preparation of high quality maintenance manuals for services and equipment. Having manuals available before the training was an important issue for the respondents, because it let them go through the training sessions having the manuals in their hands and enables them to achieve a better understanding of the facilities and services. An informant from the GCUH stated:

> "We're delivering a full set up operating and maintenance manual for this job that includes asset lists, maintenance requirements, etc. I think that's a big change to a lot of projects ... The problem is manuals are mostly

> prepared after the training, so why we're going to deliver manuals here is because we are getting the manuals for the training ..." [GCUH]

Regular Monitoring

The respondents believed that having regular monitoring, retrofitting and testing the equipment and services had a significant impact on keeping O&M staff updated. A manager from GCUH stated that compromising was an important practice in their job, because clinical needs were always in priority compared to the maintenance problems.

The increasing number of services and facilities forced O&M staff to carry out retrofitting every day. New services might not be fitted to older buildings. For this reason, retrofitting was always a regular task for O&M staff. According to the MMF (2010a), "sufficient funding should be allocated for replacing components at the end of their useful life with modern equivalents". One informant said:

> "Probably another key aspect in terms of maintenance is increase in the services which means we need new facilities and new services that are not designed into the building and we need to retrofit it." [TH]

In parallel, the respondents confirmed that testing and checking current equipment were among their everyday jobs to see how systems were performing. It is a part of commissioning to test and run building services to ensure buildings are ready for use (CWMF, 2010). A manager noted:

> "What we do there is we move around and we find out where is the service moving. What's changing? What's new? What improvements can we do on our current service?" [GCUH]

A maintenance manager at the RBWH noted that retrofitting, testings and checkups involve risks when there are patients on life support at the workplace.

Controlling the Costs

The analysis shows that practices aiming to control the maintenance costs of health projects were regularly carried out. They included seeking money from the companies that initially installed a service or equipment, optimising storage areas, using alternative maintenance methods, and using alternative materials.

There was some evidence showing that O&M stakeholders spent too much time on seeking money from the builders or those who initially installed a service or equipment. Some of them were successful in getting the builders back to fix problems and some were not. The comments made in the interviews on this point included the following:

> "... we seek money from the people who did the initial project ... We are one of the very few sites that is successful in getting builders back to fix defects." [RBWH]

> "When you got many defects, you need to bring the construction team back in. You cannot use the facilities and beside that the facilities liability period has already started." [TH]

A maintenance manager from RBWH stated that it was expensive and sometimes impossible for them to build new storage areas. It was the reason that they were supposed to "do magic" with spaces by creating new spaces out of existing ones. The evidence showed that they usually skimmed and optimised the areas to provide more storage spaces in buildings for many years:

> "We are facing with that all the time, trying to optimise, also trying to do skim to crease storage. You cannot create space. You just try to use it more efficiently." [RBWH]

The respondents also highlighted that using alternative maintenance methods and materials could considerably help to streamline maintenance processes, and increase the effectiveness of operability and maintainability implementation. The alternative materials could simply replace the older dangerous ones. They also had more durability which was a big advantage. The use of plastic sheeting was an example that was noted by a maintenance manager as follows:

> "Over the last 20 years there has been variety of techniques that people have tried. People have tried compressed fibre, various bump rails, timbers, and stainless steel or even reinforced plaster boards, either as something which is built into the wall or as a feature on the wall in order to enhance the design. Currently we are using plastic sheeting. There is formed around the corners and that's working quite well." [TH]

Another maintenance manager at the GCUH also highlighted an example of innovative maintenance technique that was used before:

> "We've built platforms in plan rooms, so instead of expecting them to bring the ladder along with them in the rooms, they can use the built in platforms! This is a big project." [GCUH]

Safety Considerations

The analysis revealed that the removal of aged, dangerous and useless materials took up a lot of the time of the maintenance stakeholders. The evidence showed that they spent much of their time and money on providing a safe environment. The removal and replacement of existing asbestos materials should be considered as a priority in the projects (SAMF, 2010a). This was also reported by a couple of respondents as follows:

> "Asbestos has been banned here for many years. There are some buildings that used to have asbestos. The policy on this site is when you go to work on a building that has asbestos; we have it removed first professionally ... There was a lot of asbestos in the building. They spent more than 10 million dollars to remove it first." [RBWH]

> "... we have removed asbestos ceiling tasks." [TH]

As mentioned previously, carpets can also cause harm to staff. Current practices implemented during the O&M stages of health infrastructure projects indicated the awareness of QH stakeholders regarding the proper O&M implementation of services, equipment and facilities. It also highlighted the need for revision of the current strategies being used.

5.4 SUMMARY

This chapter presented the initial findings from the analysis of the interviews. It explored the operational considerations from the perspective of O&M personnel in detail. The use of qualitative analysis allowed an in-depth exploration of the O&M needs of QH infrastructure projects.

The main aim of this chapter was to answer a couple of questions related to O&M problems and the current practices implemented to address them. It was found that various problems were negatively affecting the O&M of infrastructure projects, including lack of proper accessibility, lack of flexibility/adaptability, complexity, cleanability problems, safety issues, no effective standardisation, inefficient communication, poor knowledge, budget constraints, late or incomplete handover of documents, no preventive programs, and legislation and contracting problems. The different current practices implemented to address the O&M problems were summarised, including early programming, standardisation, knowledge sharing, integration of knowledge, control of the handover stage, strengthening communication, developing knowledge and experience, regular monitoring, controlling the costs, and safety considerations. These O&M problems and current practices were the basis for further development of the O&M principles that are presented in the next chapter.

Chapter 6: Operability and Maintainability Principles

6.1 INTRODUCTION

This chapter reports the rest of the findings from the semi-structured interviews (see Appendix B) that were conducted to investigate QH infrastructure projects, followed by the data collected from QH guidelines and documents (see Section 4.2.1 for the list of reviewed documents and guidelines). The purpose of this chapter is to answer the first research question:

- What are the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects?

Principle, as it is defined by the Oxford Dictionary, is "a fundamental truth or proposition that serves as the foundation for a system of belief or behaviour or for a chain of reasoning". So the principles that are targeted to be designed in this chapter are those propositions that can be considered as foundations for proper implementation of operability and maintainability during the delivery phases of infrastructure projects.

Answering this question required a clear understanding of existing O&M problems and the mitigating practices carried out in QH infrastructure projects. This chapter demonstrates the diverse evidence of current practices, along with some clear comments given by O&M professionals leading to some specific O&M principles. These principles are also supported by the available QH guidelines and documents. Wherever a statement was found to be valuable and well supported, it would be considered as a principle for better operability and maintainability implementation.

Sections 6.2 to 6.5 present the evidence from current operational and maintenance practices in each PLC phase separately. The discussion in these sections also demonstrates the direct supports given by the O&M stakeholders, and some statements from recently published QH documents or guidelines leading to the identification of valuable principles for better and more efficient implementation of operability and maintainability in different PLC phases. Lastly, section 5.6 summarises the chapter findings.

This chapter provides a reliable foundation for further extension of constructability principles to include O&M considerations in the next chapter. The derived operability and maintainability principles are considered as the main findings of this chapter that the following chapter then discusses.

6.2 OPERABILITY AND MAINTAINABILITY PRINCIPLES FOR PLANNING STAGE

QH is now aware that delivering health infrastructure projects is very expensive these days. The maintenance of health projects is also costly. It is very important to plan and design an infrastructure project for a longer life-cycle aiming to avoid early demolitions and re-planning for building a new construction. The respondents believed that there were many concerns that must be considered at the project forefront. The project planners and designers must be aware of these concerns and plan for a durable health project. As one manager noted:

> “It’s got to come to forefront because the cost of delivering healthcare services is growing, it will continue to grow, and its maintenance is now becoming quite a considerable cost. The other thing is that government is now starting to realize that that they can’t afford to go and spend 1 or 2 billion dollars to provide new infrastructure to work only for 30 or 40 years time, so now they are starting to consider all these key aspects ... It’s those types of things that have to come to the forefront which we’ve to put it embedded to mandatory policies.” [AMSU]

On this point, the CIMR (2012a) document stated that:

> In planning, designing and specifying a health facility, the recurrent costs involved in maintaining the building infrastructure need to be an important consideration.

There was plenty of evidence confirming the awareness of O&M staff regarding early planning considerations of O&M concerns. Figure 14 highlights a list of principles for the planning stage that are elaborated hereafter. These principles are the keys for more effective and efficient implementation of the operability and maintainability concepts within the planning phase of health infrastructure projects.

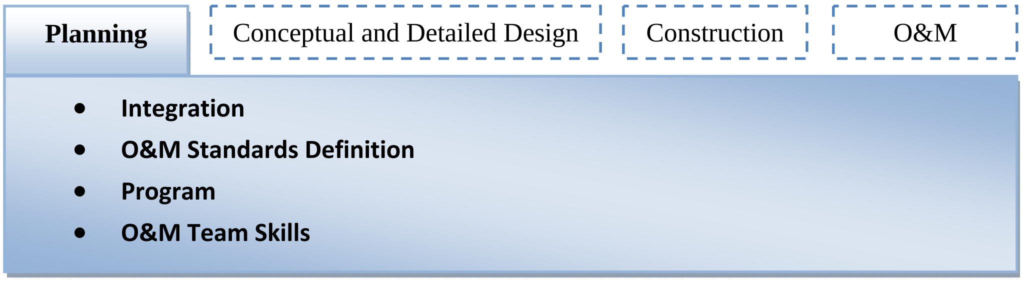


Figure 14. Planning phase operability and maintainability principles

Engineers must actively be involved in the planning and design phases. The interviews showed that project engineers can significantly fulfil the needs of project O&M phases and enrich the plans and designs with their valuable inputs. A manager said:

> "Engineers should be on those projects early for all those little decisions." [TH]

Analysis also illustrated that the participation of project engineers early in the PLC minimised disparities and extensively decreased the maintenance costs of infrastructure projects. Upfront consideration of the operability and maintainability concepts could influence how materials should be selected, how they should be serviced, and lastly how they should be operated and maintained. According to the DDMP (2005), "preliminary research undertaken as part of the project revealed that in many cases, the selection of a building material and its treatment often ignores maintenance issues". The following evidence was shared by a manager from the AMSU:

> "To drive down project cost, for instance around defect, poor designing outcomes, I mean addressing those, ensuring there is integration. By making considerations prior to commencement of the project, we can minimize the variations. Integration issues in regards to current status of system, specially when talking about water, fire, electrical, gas, air-conditioning. These are systems on a lot of hospital sites are critical." [AMSU]

> "... what I have asked for is upfront maintainability in, considerations of life cycle, design out maintenance in regards to material selection and choices, integration, standardizing fixture and fittings in brown field sites, planning the equipment, using those type of standardizations, alignment of services

> and those type of things ... Those are some of the things that we've taken in change in regards to QH." [AMSU]

As presented in the previous chapter, the O&M professionals did their best to share their knowledge and experience with the project planners and designers using different techniques, such as participation in multi-disciplinary consultation sessions, user group sessions or panels of providers. They also helped QH executive members to predict future problems. All these efforts imply how important it is to integrate the O&M concerns into the planning and design phases. Their consideration of the operability and maintainability concepts within the planning and design phases can have major impacts on the overall project objectives. Such early involvement can make considerable savings in the O&M costs of infrastructure projects, as most of the respondents agreed. The above evidence can be formally expressed in the following proposition:

P1	**Integration:** Operability and maintainability must be an integral part of the project planning and design stages.

In addition to the evidence presented about the perception of integration, setting standards for designers of QH infrastructure projects was an important issue in the eyes of the interview respondents. They believed that it was definitely a sensible expectation from QH to provide such a comprehensive standard for the project designers, because not all the designers are necessarily familiar with detailed health project specifications. A couple of managers highlighted this point as follows:

> "The QH has tried to set minimum standards. That's going out to consultation; it's internal at the moment." [RBWH]

> "... whether Queensland Health sets standards, this is what we expect and this is what we want and it's a part of contract that public works does with the contractors or whatever who is going to build it. These are the expectations ... I think it can only be through standards ..." [CHRISP]

Analysis brought to light that setting documentation standards within the planning phase led to a balance in O&M costs versus pre-occupancy phase costs. Investigation on the existing practices of the O&M stakeholders showed that a major awareness regarding this issue had recently been raised. For example, a manager stated:

> "... we need to get primary costs, operating costs, maintenance costs, refurbishment costs and retirement costs into balance ... It is in the actual initial project documentation ... Royal Adelaide Hospital which is a new hospital redevelopment is at ground level. The operations manuals are started during the planning stage, because they are using a combination of Building Information Management Systems [BIMS] that they use during design and they've already gone on board the consultant that put together these manuals. So from a plan he will get a drawing ... so he can start now finding the components of that hydraulic system, so he can allocate a set of data to it now before you start." [HIDD]

In brief, having a standard to act as guidance for the project planners and designers of health projects seems to be highly necessary. The respondents stated that such unique standardisation could significantly help the more efficient design of heath building services and their maintenance systems. The interviews showed that the AMSU was responsible to develop such policies and they were working hard to prepare such standards. This was mentioned by a manager within one of the QH corporate sections:

> "You know we have not really got provided guidance or direction probably to the design team which says hey this is the design standards we need with the building services ... Within that area, they call it AMSU; they are responsible for sitting the policy." [CDP]

The previous chapter also presented some implications showing that a movement toward consistent standardisation had already been started by some project stakeholders through different practices during PLC phases. Participation in AMSU workshops or mandatory service planning consultation sessions during the planning phase and helping to prepare a health-oriented business solution design at the design level were among these practices; however, use of the OMTRAK software to track different activities during the construction phase, and applying a streamlined instruments management or a computerised maintenance management system in the post-occupancy stage were not planned initially, but were applied and as a result had a significant influence. This indicated the need for a definition of O&M standards at the earliest possible time. This need can be formally stated as follows:

P2

O&M Standards Definition: Project planning and design must be supported with an exact definition of the O&M standards.

Decisions that are made within the planning phase provide an unchangeable structure for the whole PLC. There was much evidence showing that a program based on the right consultations was always necessary, because right and on-time consultations could guide the whole project program to be construction- and O&M-sensitive. A manager from AMSU noted:

> “Regardless of the type of the contract, if it is a QH project that we are funding, the principles should remain unchanged. They need to do it during design and planning phase, so they need to be doing the right consultations.” [AMSU]

A manager from the CDP believed that to prepare such a program, it was necessary to identify clearly what needed to be implemented in the project during the different PLC phases. Having such a detailed program could also assist in getting enough funding from government. It also prevented unrealistic planning by inexperienced decision-makers in government. The CDP manager stated:

> “I think the biggest thing is we need to find a chance to do planning which leads to a project getting approved by the government, because that really enables us to identify what clearly needs to be done and then we can get appropriate budget for doing it and a timeframe which really helps to define what is required.” [CDP]

In addition, one of the managers from the GCUH highlighted an example for programming different activities by splitting them based on the requirements of the facilities. It resulted in designing facilities based on users’ requirements. The example was given as follows:

> “Back to that power station, their focus is generation of power; healthcare system is focusing on delivering services to the public. So maintenance is pretty vital on that whole level. If that was going to be proved, what I would

suggest to be better outcome for everybody, is to split the whole thing which is to have a body that their responsibility is to deliver a facility and to have a body that is responsible for delivering the service and separate the budgets. In other words, people will design the facilities around the users' requirements ...” [GCUH]

Some of the existing practices addressing the O&M problems also implied the need for proper early programming in infrastructure projects. Doing capacity studies, planning prioritisation and having a procurement team for the selection of builders were some of those practices. This shows the awareness of the project professionals regarding the importance of early programming in infrastructure projects.

In brief, the above evidence shows that realistic and O&M-sensitive programming during the planning or design phases has a significant influence on reducing the total O&M costs. Thus, the following principle can formally be formally expressed as:

P3

Program: The overall project program must be realistic and O&M-sensitive. It must be prepared at the earliest possible time within the planning and design stages.

Making O&M inputs into the planning and design phases take place when different project stakeholders with proper levels of skill and experience are brought into the project forefront. The findings revealed that the selection of staff with relevant O&M skills and experience was essential for the planning and design consultation forums. On this point, the following comments were made in the interviews:

“The first thing is that they need to allow some inputs on the design team where they can through in. Somebody with a lot of experience can be added to the team.” [TH]

“They got to ask some experienced O&M people as part of the project team and then take notes of what those people are saying ... I think one of the critical things is employing professional people with relevant experience and you should take their advices, not be over ruled by budget constraints.” [RBWH]

A maintenance manager noted that when coming to the planning and design phases, it is more beneficial to have a mix of technicians and managers together who can make rich inputs based on their experience. This helps the project team to learn from previous mistakes, and design for the life of future buildings, not only for a short period. He said:

> "... Improvement in the construction is proportional to amount of experience and to the amount of construction that entities engaged in an experience, because you learn from mistakes ... you should get many people who are skilled and experienced, then you avoid a lot of issues. Project team is a short term team only there until the project is complete. Next gone! O&M is for the life of the building ... It is important to have both [technicians and managers], because there are problems that are created by certain people while professional engineers are more familiar with." [RBWH]

Some of the recent practices such as use of different skills in capacity studies or multi-disciplinary consultations also indicate the importance of applying the relevant skills and experience in early decision making-processes. This evidence indicates that bringing the right skills and experience to the planning and design phases is a key to carrying out the right decision-making process. It can be formally stated in the following proposition:

P4

O&M Team Skills: The skills and experiences of the project team within the planning and design stages must match the O&M needs of the project.

The next section highlights the principles for the conceptual and design stages that were derived from the interviews as the principles that can achieve a more efficient and effective implementation of operability and maintainability in health projects.

6.3 OPERABILITY AND MAINTAINABILITY PRINCIPLES FOR CONCEPTUAL AND DETAILED DESIGN STAGE

In addition to the principles that were given for the efficient and effective implementation of operability and maintainability in the planning stage (Propositions P1 to P4), there was evidence showing that the importance of decisions made within the conceptual and detailed design stages could not be neglected. This evidence supported a number of principles that are summarised in Figure 15. These principles are discussed in detail hereafter except the first four principles that are in common with the planning phase principles already discussed above.

Planning | Conceptual and Detailed Design | Construction | O&M

- **Integration**
- **O&M Standards Definition**
- **Program**
- **O&M Team Skills**
- **Accessibility**
- **Adaptability/Flexibility**
- **Authority**
- **O&M Available Resources**
- **Cleanability**
- **Engineering Methodology**
- **Functionality/Fit for Purpose**
- **O&M Knowledge**
- **Specifications**
- **Technical Leaders**

Figure 15. Conceptual and detailed design phase operability and maintainability principles

The interviews showed that consideration of operational concerns during the design phase could considerably affect the accessibility of facilities and services during the PLC. Designing alternative or short-cut routes can help maintenance staff to get to the right point in a shorter time. A good accessible project also considers the safety of operators (CIMR, 2012e, 2012h). It provides separate access paths for patients, visitors, ambulance, emergency, staff and service vehicles (CIMR, 2012f). A maintenance manager from GCUH noted:

> "Some issues like accessibility needs lots of discussions on how to improve it ... We have worked a lot on how to design the access routes and we've improved them." [GCUH]

The respondents agreed that designing an accessible health project could help O&M stakeholders to access the services and facilities without disturbing patients or other existing staff in health buildings. They pointed out that maintenance staff should keep themselves away from beds to prevent any negative influence on the treatment processes of patients. A manager commented:

> "It is more about accessibility issues. If it's done correctly, you can access that 24 hours without impacting others ... The other thing from maintenance aspect is you cannot get access as much, because you don't want to be close to beds etc ... So accessibility, that's actually covered as an extend by the Building Code of Australia [BCA], if you are aware, but it got to look at maintainability.." [RBWH]

Holding different user group sessions within the schematic or detailed design stages was among implemented practices that helped O&M professionals to make the project designers aware about the accessibility difficulties or other similar problems that they faced every day. This implies that consideration of accessibility during the schematic and detailed design stages of health infrastructure projects can positively influence the O&M costs. This evidence leads to the expression of a proposition as a formal statement as follows:

P5

Accessibility: Operability and maintainability will be enhanced if accessibility is considered in the conceptual and detailed design phases.

According to CIMR (2012b), "it is accepted that change is inevitable and that it is difficult to predict with any degree of certainty how future requirements will impact on the delivery of health services and the configuration of facilities"; however, being adaptable or flexible was considered as an important issue by many of the respondents. A properly designed health project should be future-proofed in order to minimise probable adaptation costs, and therefore it can manage the changes (CIMR, 2012e, 2012i). It should identify future treatment works to find out priorities and cost estimations (MMF, 2011). One manager highlighted the example of a case where maintenance staff faced extreme problems. He said:

> "... you are relying flows of services, actually you are trying to line them to limit things like where you've got change of direction or access or things like that, that becomes problem, that causes maintenance problems." [AMSU]

Infrastructure projects should be able to be easily modified to respond to changes and expansions (CIMR, 2012f). When you have a flexible/adaptable design based on users' experiences and skills, it is much easier to make changes, as one respondent commented:

> "We recently use the users' experience to design the buildings and we simply change the design based on their feedback." [GCUH]

A maintenance manager at TH believed that the flexibility/adaptability issue gets more critical when it is the matter of health projects rather than other project types. He stated:

> "It is a moving target of change in those issues. Maybe it's a little bit different in the shopping centre, but in hospitals I would think that you really need to have the kind of I suppose flexibility built in some of the areas." [TH]

Another manager raised an example of a successful experience in regard to consideration of flexibility of multi-faceted labs within the design stage. The evidence shows that having a variety of equipment and services in labs made it difficult to anticipate how the design sketches should exactly look; however, early consideration of flexibility concerns had considerable positive influences. He noted:

> "Labs are very service rich. You can't often say what equipment you have in a particular area. That is why we are working at the base level of design phase to make sure we have enough power, data, etc and to check if we can move them around in case there is any change in place of the equipment. This is more about flexibility of service design." [HIDD]

Some other maintenance managers highlighted some examples as follows:

> "To make a new hospital building totally flexible, you have to go back to some old forms of construction. You need to build concrete slabs with a rough finish and put a screen on top of them, because when you change the purpose of the building, you can cut the screen out, you got the facilities ..." [TH]

> "For example power is always used somewhere in the hospital and you should be able to access some sections safely without turning whole the power off, and because of a lot if moving targets, it will change accordingly." [RBWH]

> "Let me give you an example about Royal Adelaide Hospital. They said this hospital is going to be patient centred ... In Adelaide hospital patient will not leave at all apart the surgery, and the doctors will come to him, so the rooms have to be bigger because the doctors have to bring the equipment." [HIDD]

Probably one of the biggest issues raised by the respondents in regard to adaptability/flexibility was change management. Medical devices are mostly used for a short period of time and usually changed periodically, so there is a significant need to design infrastructure projects that are adaptable enough. In the QH infrastructure project, this had been practised through user group sessions. A manager commented:

> "... medical imaging equipment, what's going to be put in for 5 to 10 years is going to change, so it means you should have flexible installation. That's just basically a generic type; it's going to be a flexible design." [RBWH]

In brief, ensuring the flexibility/adaptability of designs is a type of future-proofing for infrastructure projects. This can be stated formally as follows:

P6

Adaptability/Flexibility: Operability and maintainability will be enhanced if adaptability/flexibility is considered in the conceptual and detailed design phases.

It was also observed from the interviews that enough authority should be given to O&M stakeholders. The respondents thought that having some authority enabled O&M staff to make proper inputs into the design phase. They believed that the lack of sufficient power to make changes caused their inputs not to be taken seriously. A maintenance manager noted:

> "... the thing is they should have authority as well, not just advices and then see what happens! They should be given authority ... there needs to be authority and input from people who got the life of the building." [RBWH]

One manager described it as a gold class option which was not often easy to achieve. He said:

> “That is usually said as the gold class option, but often times that ideal situation doesn’t present itself ...” [TH]

The data also suggested that there were many controls on how O&M stakeholders were involved in the design or construction site offices. It indicates that O&M staff lacked enough power to make changes in the conceptual or detailed design phases. On this point, a manager said:

> “There are very controls on how we are working in project office and any communications, they are aware of ... Our problem is that because there is a project office which we’re not officially part of it, we don’t get all the information .... we lack the authority of ability to make changes.” [HIDD]

Appointing an experienced maintenance manager as the project manager in a new project might be an option in order to consider O&M concerns in the planning, design or even construction phases. This was recently practised in some QH infrastructure projects, and they seemed to be successful. A manager highlighted:

> “On large projects, you can set a maintenance manager as a project manager to bring maintenance issues into planning, design or even construction phase ...” [RBWH]

On the contrary, another maintenance manager argued that there should be some O&M professionals focusing on the planning and design of every single project, rather than giving power to the O&M staff of other projects to join the planning and design of future projects and expect them to spend much of their time being active. This was elaborated upon by a maintenance manager as follows:

> “Not necessarily, authority should be included ... Somebody with a lot of experience can be added to the team as a buildability or maintainability consultant on the team ... There are probably only a few people that could fulfil that role adequately. It would have to be their only job ... Somebody has to do it. It doesn’t have to be a person of the top. Somebody has to delegate that task.” [TH]

Most of the respondents from both the QH corporate and district sections agreed with the merit of giving a logical amount of authority to experienced O&M staff in earlier project phases, because they are people who can really make effective inputs into the planning and design phases. They believed that this can significantly help to enhance implementation of the operability and maintainability concepts. This proposition can be formally expressed as follows:

P7

Authority: Operability and maintainability can be enhanced if enough authority is given to O&M stakeholders in the conceptual and detailed design stages of future projects.

Project designs should be based on available resources, so the selection of materials and equipment to be used within the O&M of health infrastructure projects should be based on the available skills and budget. One manager noted that there was no principle for it previously, but newly published QH regulations and guidelines added some principles defining how the technology of design solutions should match the available materials, skills and resources. He also commented:

> "Fundamentally once we followed the principles of what TS11 is, what I have asked for is upfront maintainability, considerations of life cycle, and design out maintenance in regards to material selection and choices ... That's now embedded into the principles." [AMSU]

One respondent gave an example of what happens when design is not based on the available skills and experience:

> "During the schematic design, there were 10 user group meetings. There were not enough resources. The people they had like global responsibilities for services and staff and tend to move between meetings. We didn't sit in whole meetings." [GCUH]

One of the major practices highlighted by the respondents was to provide a range of equipment and resources to the project designers. This indicates the significance of matching the plans and designs with the skills, equipment and resources, which can be formally stated as follows:

P8

O&M Available Resources: The technology of the conceptual and detailed design stages must be matched with the skills and resources available within the O&M phases.

A simple design should keep the project clean for a long period. Health infrastructure projects are usually very clean at the beginning, but as time passes, the facility starts to get dirty and needs to be kept clean and hygienic. A proper project handover should ensure environmental performance is efficiently maintained over the PLC (SAMF, 2010c). Two informants stated:

> "Very simple design should keep everything cleaned like corridors, so you are not seeing wastes going out in front of public area, or even by designing some rooms to keep wastes, separated in a place that they can safely store waste material and it won't impact on anyone." [RBWH]

> "I think cleanability of the project early after construction is usually good ... The cleaning I was talking about is about after 8 years time or 10 years time when we start to get dirty duct works." [GCUH]

A project manager highlighted that the type of materials selected during the design phase could significantly affect how easy or hard it was to keep the operating project clean. He continued that the selection of materials during the design should be based on the past experience of the O&M staff who were in direct contact with the operational issues. He said:

> "We have gone through other hospitals which they have had different experience of other materials used." [GCUH]

The data also suggested that it is very important to bring the real cleaning stakeholders of infrastructure projects into the design phase and ask them to make beneficial inputs for better material selection. Cleaners might be one of the lowest paid staff in hospitals; however, they can have considerable impacts on the selection of suitable materials that can be easily cleaned. Manuals or guidelines should not try to replace these consultation sessions, but to enhance them (CIMR, 2012a). One manager said:

> “QH will have the cleaner sitting there with the engineer [through multi stakeholders consultation sessions], and the cleaner will say no no no! Don’t put the small tights into the bathroom, because it is very difficult to clean and I really can’t do it!” [TH]

Consideration of cleanability concerns during the conceptual and detailed design phases is a key principle for ease of O&M in health infrastructure projects. As mentioned earlier, holding user group sessions during the design phase had helped the project owners bring cleanability ideas to the attention of the project designers. This indicated how effective the concept of cleanability is from the O&M aspect. It can be formally stated as follows:

P9

Cleanability: Operability and maintainability will be improved if cleanability of the project is considered in the conceptual and detailed designs.

The design of multi-faceted infrastructure projects like hospitals must consider the engineering methodology used within O&M phases. This view was shared by most of the respondents. According to the CIMR (2012h), “engineering services approximates to around half the capital development cost of a health facility for new construction. Cost effective engineering design is therefore critical to achieving projects within budget”. There are plenty of complicated devices and equipment that are regularly used during O&M phases. Each piece of equipment needs a clear and straightforward manual or guideline. The following comments were made in the interviews in relation to this point:

> “I think what needs to happen is a need to have a clear guideline of what we need.” [CHRISP]

> “Management of operational manuals and maintenance manuals of what which are installed is important.” [RBWH]

QH recently made a lot of effort to come up with the Capital Infrastructure Minimum Requirements as a new comprehensive guideline in order to cover what the TS11 had previously covered, but this time for the state of Queensland. The CIMR contains many details including the engineering methodology of post-construction stages that can considerably help the project designers to design for the right engineering method. QH infrastructure projects must comply with the CIMR to get approval for continuation of their work (CIMR, 2012a). The following statements were made by the respondents regarding the CIMR:

> "This manual will be the minimum requirements that everyone must comply." [CDP]

> "We are just about settling the engineering guidelines ... We are actually in the starting point, and that has already been done with cooperation of NSW health and been helped by TS11 guidelines." [AMSU]

In brief, consideration of the engineering methodology at the design stage can lead to a cheaper and easier O&M process. This can be formally stated as:

P10 **Engineering Methodology:** The project design must consider the O&M engineering methodology.

QH has recently introduced a three step procedure for having a functional design. First, designers should have access to online manuals and relevant checklists. Second, a strategic level of manual sections should be completed and submitted to QH together with the checklists for assessment, and lastly, a fully functional design is developed and submitted to QH for final assessment and approval (CIMR, 2012a). In this process, it is very important to understand the purpose of the project that is being designed. When project purposes are clearly defined, a functional and comprehensive design can be implemented. This view was expressed by a maintenance manager as follows:

> "It doesn't matter how well maintainable equipment are, operationally if it doesn't do what their purpose is, it needs to be changed." [RBWH]

Understanding the project purposes should be clarified right from the planning and design stages via a functional design brief. Earlier decisions will have greater influences. This was also noted by a manager within the corporate section of QH:

> “Right from project definition planning, we had to produce a functional design brief.” [HIDD]

Designs must be based on the real needs of the project. It has always been a big issue for the O&M managers of hospital projects to find out the real needs properly. A manager claimed:

> “They should design to suit the needs. They actually don’t design for what we are doing.” [TH]

He continued:

> “Completion means fit for use, fit for the practical purpose which the building was intended ... When the project needs more money and they don’t have it, they just try to finish it with their lower budget ... [it] produces incorrect functionality of the building and pity use of it.” [TH]

According to the collected data, the review of project purposes has been practised extensively during the planning and design stages of health infrastructure projects, and has had considerable positive influences. This implies that the functionality of every single project should be explored as early as possible. Designs should all fit the real aims of a project and fulfil its requirements. Formally stated, this can be expressed as follows:

P11

Functionality/Fit for Purpose: Operability and maintainability will be meaningful if functionality is considered in the early planning stage and if designs are fitted for real project purposes and needs.

The evidence from the interviews showed that there was limited O&M knowledge within the conceptual and detailed design phases. The planning of health facilities and equipment requires knowledge of the proper relationships between different components (CIMR, 2012e). The interview data showed that there was a significant need to bring relevant operational knowledge to the early phases in order to transfer the O&M knowledge and enrich the designs. As long as the corporate personnel do not take external advice from technical staff, the guidelines and as a result the designs will not be O&M-sensitive, as stated by some informants from the corporate section of QH:

> "It came from where we felt there has been a gap for a number of years that we do not provide good direction to the design team around what our requirements are. You know they do not have detailed knowledge, so we need those sorts of things ... we need to get external advices to understand technical experts." [CDP]

> "I honestly think the level of knowledge in this area is really limited!" [CHRISP]

On the other hand, the evidence indicated that QH had good experience in bringing operational concerns into the design or even construction phases of health infrastructure projects. The GCUH, under construction at the time of writing, was one of the most prominent examples. The following comments were made by the respondents:

> "We've got a good knowledge base, bringing experience from working labs, and saying what needs to be put in design ... The people who are in O&M section do need to be onboard early to get that through and see the benefits in that." [HIDD]

> "GCUH has actually employed several hospital engineering people on the construction team ... They bring lots of experiences and practical knowledge." [TH]

However, it remains clear that involving O&M stakeholders in the design or construction stages is not easy. There are many negative forces that might prevent the effective involvement of the stakeholders. One engineer described the experience of not being allowed to get involved in the construction site appropriately:

> "When I got to Logan, I replaced a fellow ... He just went through major extensions, he wasn't allowed on the construction site for the whole construction period. Because engineers find the problems, they want to get things fixed up and they want to make changes." [HIDD]

Having access to accurate data on the performance and operation of buildings is essential for proper planning (SAMF, 2010a). This evidence indicates that bringing

O&M knowledge into earlier project phases is essential. It can be formally stated as follows:

P12

O&M Knowledge: Project conceptual and detailed design must properly involve O&M knowledge and experience.

Locating a health project and all other detailed information on how to build and deliver the project requires the correct analysis of project specifications. As noted by some respondents, the development of project specifications can significantly affect the efficiency of O&M phases. A manager at the GCUH highlighted some of their activities during the project definition and planning stages to organise different project specifications. The following comments from the interviews provided evidence confirming the importance of the early consideration of project specifications:

> “... what we’ve done is taking into other considerations like physical considerations, for instance you don’t go and put a building right next to the sea, not for health care building. Those are some of the things that we’ve taken in change in regards to QH.” [AMSU]

> “It is probably ensuring that there is some consistency and robustness behind actual design and it is functional and appropriate for where it is going, whether it is along the coast, up north, in-land, wherever, and it suits to local conditions, temperatures, etc.” [CDP]

If the specifications are defined early enough, it will result in achieving high quality products and selecting the right materials, as noted by an informant:

> “Unless you have really good specifications, you will get the cheap products ... I think unless you actually specify the level that you want, you won’t achieve the right materials.” [CHRISP]

Reviewing the documents during the planning and design stages can help to develop project specifications more efficiently. Defining the specification should be in lay language so that everyone can understand it. A maintenance manager explained this point as follows:

> "I think document review is extremely important. If I am reading these specifications, and it is written in nurses' standards specifications, I am not going to understand those specifications. You need to have a plain language type document that people can understand." [TH]

As the CIMR (2012b) explains, Queensland has diverse climate conditions. It means "the effects of the climate on the project will be specific to the climate zone the project is in, and potentially very different to a project in another area of Queensland". This indicates the importance of the selection of the project location, based on the project specifications. In brief, health infrastructure projects must have evidence-based designs (2012e). These points highlight the significance of caring about project specification, which can be formally stated as follows:

P13

Specifications: Operability and maintainability are enhanced when the efficiency and effectiveness of O&M phases are considered in the development of specifications.

Health projects often lack technical leaders for the conceptual and detailed design phases. The respondents mostly agreed that project designs were usually managed and controlled by architects, and this had often caused problems for the O&M of infrastructure projects. The respondents believed that there might not be a significant need to have technical leaders involved at the initial schematic design stage, but it is very important to take a team approach when the detailed design phase starts. The evidence showed that architects were often the stakeholders who led the design of health infrastructure projects. Some of the comments related to this point are as follows:

> "All too often what is happening at the moment is that when they form these design and planning teams they are led by architects, so it is a wrong way to go! ... The architects shouldn't take the lead. They should be a part of the project." [AMSU]

> "Architects do functional diagrams, but unless you have a clear understanding of what is involved, you can't design for that service...

architects like to makes it pretty that it looks good and that sacrifice serviceability for the sake of beauty.” [TH]

“I think it needs to be a team approach. At initial stage really early on to get how much space you require, engineers are not necessarily needed for that stage, and next stage when we get through schematic design, what we did was a team approach which there were architects, engineer consultants, etc. But the problem is architects are mostly the decision makers.” [HIDD]

Overall, this indicates that having technical staff as the leaders of design teams can significantly enhance the operability and maintainability implementation during the design phase. This can be formally stated as follows:

P14

Technical Leaders: Having technical leaders instead of architects as leaders at the early conceptual and detailed design stages helps to achieve the enhanced implementation of operability and maintainability.

The next section highlights principles for the construction phase that were derived from the interviews to achieve the more efficient and effective implementation of operability and maintainability in health projects.

6.4 OPERABILITY AND MAINTAINABILITY PRINCIPLES FOR CONSTRUCTION STAGE

A good construction phase considers maintenance issues in order to make savings in the post-occupancy stage. The wide range of practices performed by the O&M stakeholders during the construction stage highlights its importance. Two principles that were frequently echoed by the respondents are presented in Figure 16, and are discussed accordingly.

Figure 16. Construction phase operability and maintainability principles

The benefits of having O&M staff with enough authority in the design phase was discussed earlier (Proposition P7), but it is interesting to note that the respondents believed that having enough power to be effective during the construction phase was as important as having that power in the design stage. They thought that most of their concerns during the construction phase were not considered seriously, because they did not have any pre-defined position in the construction phase. The evidence showed that QH was changing many old viewpoints and had become aware of the significance of the integration of maintenance inputs into the construction stage. A manager said:

> "I think it is already possible, it is already changing. GCUH did it, the new Children Hospital has already got engineering embedded into the project team, and I am more than aware that the same will be happening in Sunshine Coast University Hospital." [AMSU]

As an example, the GCUH project gave enough authority to a maintenance manager to work as the project manager of the construction site. This enables construction contractors to get O&M inputs from a highly experienced maintenance manager. This comment was shared by a manager as follows:

> "The thing is X [a previously maintenance manager] is a project manager and he has authority in his position." [TH]

Some of the practices reported to be implemented during the construction phase of recent health projects also indicate the importance of giving a logical amount of authority to the maintenance managers at this stage of the PLC. The maintenance manager became involved in the construction management team's decisions and had many interactions with the project builders. There was also evidence that some infrastructure projects that were under construction had quickly established their maintenance units on the construction site in order to make their maintenance staff familiar with the construction and installation of services and facilities. The proposition informed by the accumulated evidence can be formally stated as follows:

P7

Authority: Operability and maintainability can be enhanced if enough authority is given to O&M stakeholders within the construction phase of future projects.

When the construction phase comes to an end, it is critical to provide completed documentations and manuals to the relevant O&M staff. QH has recently published a standard for the necessary documents that should be prepared by the designers and contractor for maintenance stakeholders prior to the project handover (CIMR, 2012h). A weak handover results in financial, operational, design, and health and safety risks (CWMF, 2010). The evidence gathered in the current study indicates that the handover task tended to be carried out poorly. For example, it was stated in the interviews that manuals and documents were given to the operational staff of the RBWH very late. An informant said::

> "The other challenge which we heard from RBWH is actually ensuring that there is an appropriate handover of documentation ..." [CDP]

Apart from that, the training was also poorly conducted. A manager said:

> "... they had the contract with the company which provided the equipment. It was done about a month or 2 months or whatever. The time that it opened, the staff had no idea what to do, so to bring the company back to do the training, they had to pay for it." [CHRISP]

When there is weak documentation and training, it is difficult to force contractors to come back and fix the problems. Two respondents from RBWH made the following comments about the problems that they faced in this regard during the past years:

> "... as you know there are many things that are not in the contract which can't be enforced to them ... it is very important to bring everything in the documentation, because if it is not put to the end users, that information is lost." [RBWH]

> "Drawings and manuals sometimes are not of good enough standards at times. Yeah! This is to work out what is best required at the time, and this needs to be documented in the specifications, and you know, the payment should be held back until those documents are delivered." [RBWH]

According to the CWMF (2010), "an efficient handover strategy will also ensure the required building information and knowledge is transferred from the design and construction team to the operational and maintenance staff, improving the latter's ability to manage the short and long-term performance of the building". Lack of proper documentation during the project handover imposes extra costs and delays on the project O&M teams. This view was shared by a manager in the corporate section of QH. He also highlighted that engineers can find things much faster if all the details are written in the documents in the right manner. They can also save time if they are well trained for each specific service or facility in the project. He noted:

> "... it [good documentation] will affect on the cost and reducing time delays, because we'll be finding things that were documented well by the engineers." [HIDD]

Training is a good solution to keep the O&M staff updated about the newly installed services and facilities, but it seems that they are usually so busy with their daily maintenance jobs that offering the training might not be that beneficial. This view was shared by an experienced maintenance manager as follows:

> "...phones go and these many maintenance issues around the hospital, it is a very difficult thing to adequately deliver training on a new building. We definitely need more of it and it is a challenge." [TH]

The respondents also highlighted two of their current practices, namely: to keep an eye on the OMTRAK software to monitor the construction stage activities; and to do some after-construction final checkups to ease the handover stage and the post-occupancy stage maintenance processes. This evidence highlights the significance of the proper and complete handover of documents and manuals to the O&M team by the project builders. This can be formally expressed in the following proposition:

P15

Handover of Documentations: Project construction stakeholders must properly hand over the completed documentation and manuals to the O&M staff.

The next section highlights the principles for the O&M stages that were derived from of the interviews to achieve a more efficient and effective implementation of operability and maintainability in health projects.

6.5 OPERABILITY AND MAINTAINABILITY PRINCIPLES FOR O&M STAGES

The participation of many staff with different backgrounds in diverse practices within the O&M phases indicates the significance of preventing the problems that many projects suffer from. This section elaborates upon the two principles that were highly supported by the respondents. These principles are presented in Figure 17.

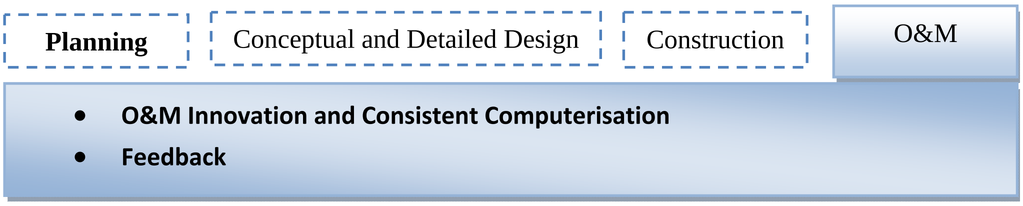


Figure 17. O&M phase operability and maintainability principles

The respondents believed that using innovative methods during the O&M of health projects could significantly help to resolve many problems during the post-construction stages. The use of technology and equipment should be maximised in order to improve the patients' care system (CIMR, 2012b). The CIMR (2012h) states that "all benchmarked project elements shall include allowance for innovation and advancement in engineering design". One manager gave an example that highlighted how the use of innovative techniques can significantly affect operational activities:

> "We've built platforms in plant rooms, so instead of expecting them to bring the ladder along with them in the rooms, they can use the built-in platforms." [GCUH]

Another manager pointed out that a variety of maintenance management systems and software were used in different hospitals, whilst there was a significant need to have a consistent computerised system for O&M of health infrastructure projects. Having a consistent computerised maintenance management system leads to cheaper maintenance procedures. It also facilitates cost sharing. A maintenance management framework should be defined prior to project handover in order to determine building maintenance requirements (CWMF, 2010). This helps to identify the proper practices for the maintenance of buildings (MMF, 2010b). A manager noted:

> "... the larger hospitals had a range of these things like MEX, BIEMS, MIM and in fact we had some fights with some hospitals for them to drop that and

put in a consistent computerised maintenance management system ... we will be able to cost minor projects, do external projects or buy an external project, will be able to do cost sharing much easier with much more definitions, so we are sort of going to next step." [HIDD]

The respondents also reported some practices in regard to the use of alternative and innovative materials or techniques that showed how much the maintenance teams were concerned about their daily maintenance costs. All this evidence indicates the importance of having a computerised maintenance management system, and using innovative methods, in order to decrease the potential problems within the post-occupancy stages. This can be formally stated as the following proposition:

P16

O&M Innovation and Consistent Computerisation: The use of innovative methods during O&M, and consistent computerisation, will enhance the implementation of operability and maintainability.

The respondents were in consensus regarding the importance of giving feedback to early project phases, because they believed that the project designers did not necessarily have clinical backgrounds, and consequently they needed to get inputs from experienced staff, O&M personnel or clinicians. The feedback should be given to make facilities and designs more patient-focused, and provide good background information for everyone including, patients, families and carers (CIMR, 2012b, 2012e). The feedback can be in the form of manuals or guidelines for the project designers. Some managers from both the corporate and district sections of QH commented on this point as follows:

"So the first thing is the user feedback that this is not working ..." [AMSU]

"During meetings we get more feedback." [HIDD]

"If there is a descriptive manual for the designers, that would be quite good, because they know what to design, and they go away and do it, rather than get the crystal ball and say this is what I think you should have or just copy and paste something!" [RBWH]

It was also noted by the respondents that feedback should not only be sought after finishing the construction phase, because feedback must demonstrate how the designs have worked in the long-term, not in a short period. One maintenance manager commented that when the operating project goes further than 2 years, the services will mostly be out of warranty and the service delivery will have slightly changed, so people's feedback would be different from the initial feedback. In line with this, the MMF (2010a) states that "departments should ensure that a rigorous review of their maintenance budget is undertaken each year". One manager suggested in the interview that taking feedback in 6 weeks, 12 months and also after 2 years would be beneficial:

> "The other thing is that at the end of the project, we need to come back and review not 6 weeks after the project, but we need to come back after 12 months, and we need to come back after 2 years and see how the building is performing, see how the design is working ... I think the other thing is we don't do enough review after. You need to do one in 12 months and another in 24 months, so doing on 12 month the building is coming out of warranty, everybody wants to move on, but in 2 years time the service delivery has changed slightly" [TH]

Post-occupancy evaluation and review of the projects increases the functionality and cost-effectiveness, improves building maintenance management and enhances operational processes (SAMF, 2010e). Taking feedback from O&M stakeholders during different operational time periods provides valuable inputs to future project planning and designs, and helps to design for the right purposes. This can be formally expressed as follows:

P17

O&M Feedback: Operability and maintainability can be enhanced in similar future projects if a comprehensive O&M phase analysis is undertaken by the project team.

The identified operability and maintainability principles are briefly summarised in Table 5. The respondents believed that the proper implementation of these principles within each project phase has a substantial influence on the effective and efficient implementation of the operability and maintainability concepts in the delivery of health infrastructure projects.

Table 5. Operability and maintainability principles

Operability and Maintainability Principles	Typical PLC			
	Planning	Conceptual and Detailed Design	Construction	O&M
Integration	Relevant	Relevant	Moderately Relevant	Moderately Relevant
O&M standard definition	Relevant	Moderately Relevant	Not Relevant	Not Relevant
Program	Relevant	Relevant	Moderately Relevant	Not Relevant
O&M team skills	Relevant	Relevant	Not Relevant	Not Relevant
Accessibility	Not Relevant	Relevant	Moderately Relevant	Not Relevant
Adaptability/Flexibility	Not Relevant	Relevant	Moderately Relevant	Not Relevant
Technical leaders	Not Relevant	Relevant	Not Relevant	Not Relevant
O&M available resources	Relevant	Relevant	Not Relevant	Not Relevant
Cleanability	Not Relevant	Relevant	Moderately Relevant	Not Relevant
Engineering methodology	Moderately Relevant	Relevant	Moderately Relevant	Not Relevant
Functionality/Fit for purpose	Not Relevant	Relevant	Moderately Relevant	Not Relevant
O&M knowledge	Moderately Relevant	Relevant	Moderately Relevant	Not Relevant
Specification	Not Relevant	Relevant	Not Relevant	Not Relevant
Authority	Moderately Relevant	Relevant	Relevant	Not Relevant
Handover of documents	Not Relevant	Not Relevant	Relevant	Moderately Relevant
O&M feedback	Not Relevant	Not Relevant	Not Relevant	Relevant
O&M innovation and consistent computerisation	Not Relevant	Not Relevant	Not Relevant	Relevant

Legend: Relevant Moderately Relevant Not Relevant

As shown in the table, most of the principles specified by the respondents are to be implemented within the planning and design phases and a few principles were mentioned for the construction and O&M phases. This verifies that the O&M stakeholders of QH have consensus on the beneficial use of preventive methods rather than remedial actions after severe mistakes have been made.

The table also shows that there some principles were relevant to two different project phases rather than one phase only. It is important to consider these principles in each separate phase in order to achieve the best possible outcomes for a project.

6.6 SUMMARY

This chapter reported the rest of the findings from the first stage of data collection. Specifically, the chapter answered the first research question: What are the principles for effective and efficient implementation of operability and maintainability during the delivery phases of infrastructure projects?

This chapter analysed the collected data from the interviews and some of the relevant QH guidelines to explore any capabilities for proper operability and maintainability implementation in the health projects. After assessment of the practices implemented by the O&M project stakeholders to address O&M problems during different delivery phases of the PLC, it was found that QH was aware of the need to open new paths for O&M professionals to make proper inputs into the early planning, design, and even construction phases of a project in order to ensure efficient and effective operability and maintainability implementation.

A list of the operability and maintainability principles regularly highlighted by the respondents was produced. It was found that most of these principles should be implemented within the early planning and design phases, whilst the rest were highlighted for the construction and O&M phases. These principles – of integration, O&M standard definition, program, O&M team skills, accessibility, adaptability/flexibility, technical leaders, O&M available resources, cleanability, engineering methodology, functionality/fit for purpose, O&M knowledge, specification, authority, handover of documents, O&M feedback, and O&M innovation and consistent computerisation – are used for further extension of the constructability principles as discussed in the next chapter.

Chapter 7: Discussion and Implications – Development of Construction, Operation and Maintenance Ability Model

7.1 INTRODUCTION

This research developed the Construction, Operation and Maintenance (COM) Ability Model which improved the effectiveness and efficiency of the operability and maintainability of infrastructure projects. As discussed in this chapter, the model extended the constructability concept to include O&M phases using the case study research method. It provided a step towards a better understanding of the complexity of O&M concerns in multi-faceted health infrastructure projects.

This chapter presents the answers to each research question and provides a bridge to the conclusions of the overall research problem. Firstly, this chapter reflects on the findings presented in Chapters 5 and 6. Secondly, it shows how the integration of different project phases through the developed model can improve the effectiveness and efficiency of the operability and maintainability implementation. Practical implications are also highlighted along the assessment process.

7.2 UNDERSTANDING OPERATIONAL AND MAINTENANCE PROBLEMS AND PRACTICES

It was found that O&M professionals from both the district and corporate sections of QH were confronted with numerous daily problems in implementing the O&M activities. Most of them, however, were pessimistic about any future improvements in their organisation's incorporation of O&M concerns in early phase planning. It was believed that this situation would persist despite the evidence suggesting that the corporate sections of QH were well aware of the importance of the early involvement of O&M, and the positive impact of this involvement on performance.

The discussion in Chapter 5 (Section 5.3) revealed that many O&M problems - such as improper accessibility, lack of flexibility/adaptability, complexity, cleanability problems, safety issues, no effective standardisation, inefficient communication, poor knowledge, budget constraints, late or incomplete handover of documents, no preventive programs, and legislation and contracting defects - were the result of the lack of integration of the various project phases. This is consistent with early studies that aimed to integrate different project phases into a unique framework (Al-Hammad, et al., 1997; Assaf, et al., 1996; Dunston & Williamson, 1999; Geile, 1996; Griffin, 1993; Ivory, et al., 2001; Lam, 2007; Russell, n.d.).

The discussion in Chapter 5 (Section 5.4) confirmed the importance of integration whereby all the O&M stakeholders have the opportunity to participate in the earlier project phases. Through this process, project improvements can be achieved using various techniques such as early programming, standardisation, knowledge sharing, integration of knowledge, control of handover stage, strengthening communications, developing knowledge and experience, regular monitoring, controlling the costs, and safety considerations. These techniques can provide a pathway for closer relationships between all project stakeholders.

The examples given by the respondents regarding the current practices they perform (Chapter 5, Section 5.4) and the supportive quotations given by the interviewees (Chapter 6) show that O&M stakeholders have had some opportunities to join the on-site project management offices and provide rich inputs to the construction phase of the health facilities and services. In addition, O&M professionals have been given more authority to be involved in the construction decision-making, and were allowed to partially check the manuals and documents before the project handover. For this purpose, there is a significant need to allocate a sufficient budget for the project handover stage (CIMR, 2012j). Such involvement enhances the contractor's knowledge about O&M problems, facilitates more effective communication, and avoids the late or incomplete handover of manuals or documents. Geile (1996) confirms that such early consideration of the O&M problems during the construction and handover stages makes many savings. The GCUH project, for example, recently used this strategy, and reported significant outputs.

The O&M professionals who participate in training workshops, with manuals and other relevant documents in their hands, will gain more knowledge of project facilities, equipment and services, while providing a safer work environment and allowing them to propose preventive programs. The 'Construction 21' report by Silva et al. (2004) confirmed the benefits of training workshops and proposed that on-time training sessions for O&M stakeholders is one of the key factors for successful operability and maintainability implementation. Analysis of the data in the present study, however, revealed no such benefits as the suppliers of health equipment and services provided limited training to O&M staff, and such training was usually conducted very late and no manuals were provided.

This research confirms the benefits of fit for purpose design as emphasised by Trigunarsyah and Skitmore (2010), wherein the early involvement of O&M professionals in the planning and design phases provides a clearer understanding of what upstream staff actually need. This research argues that although many respondents from the corporate sections claimed that QH did implement preventive programs by incorporating O&M ideas into the early planning and design stages, there were still inadequate incentives for O&M staff to join these programs, and as a result, O&M costs were always underestimated. The respondents' discussion of the GCUH project, for example, revealed that a fit for purpose design significantly assists in finding innovative techniques, materials and equipment to prevent the flexibility, adaptability and accessibility problems. It decreases complexity of the designs and provides an easily cleanable project which can be hygienically maintained. This view is supported by Lam (2007) who suggested that a maintenance program can be fully successful if the design is simple enough to be understood and have sufficient flexibility for the changing client needs.

Such strategies are likely to be more effective when they are supported by consistent and pre-defined standards and instructions. Changing instructions, such as safety constraints, decrease the speed of O&M procedures. On the contrary, the establishment of fixed standards prevents ad-hoc change, and consequently eases the implementation of O&M activities. New guidelines and standards, like the QH Capital Infrastructure Minimum Requirements, as one of the most recent standards, aim to create a strong platform for a more fit for purpose design and construction of projects. Use of such updated guidelines at the planning or design stages helps to provide preventive programs for the construction and O&M phases. Improvement of the current strategies and standards allows the integration of more operational and maintenance inputs into the early project phases (Ivory, et al., 2001; Shen, 1997). One respondent from the GCUH project commented that the use of such improved standards should be made mandatory in the contracts in such a way that all the project stakeholders have to follow it. This approach was also evident in the study conducted by Yu et al. (2006) which found that compulsory early programming and standardisation - which are very complex and iterative processes to identify the real needs of the clients and project users - have a significant influence on the prevention of O&M problems.

Overall, these findings are consistent with the notion that project clients/users are among the key people whose high level of satisfaction is a measure of project success (de Wit, 1998), and the current practices implemented to address O&M problems are aimed to provide such satisfaction to them. To intentionally manage the full involvement of the relevant O&M professionals in the early PLC phases is challenging; however, it is possible to improve conditions for better knowledge transfer. Using appropriate techniques for this purpose is necessary, and their impacts are discussed in the next section.

7.3 IMPACTS OF INTEGRATING OPERATIONAL AND MAINTENANCE INPUTS INTO EARLIER PROJECT PHASES ON PROJECT PERFORMANCE

The O&M problems in health infrastructure projects and the current practices implemented to manage them highlight the need to evaluate the impacts of O&M integration inputs into earlier project phases on project performance, and improve conditions for a better O&M knowledge transfer process. Heising (2012) and Khurana and Rosenthal (1997, 1998) stated that integration of knowledge within different project phases is usually underexposed or underestimated. A properly implemented integration leads to a higher level of stakeholders' involvement in earlier PLC phases. The data in the present study showed that the respondents were aware of the significance of operability and maintainability implementation; nevertheless, their understanding of the issues was constructed through experience, and not based on QH guidelines, standards or any other documentation.

On the other hand, there were no contractual obligations to force the O&M professionals to reflect on the implementation of operability and maintainability. When project stakeholders are regulated by a contract, the O&M ideas can simply be integrated with the pre-occupancy project phases, resulting in an improved management of time, cost and quality performances in the O&M phases. The remainder of this chapter assesses the impacts of integrating O&M inputs into earlier project phases (Propositions 1 to 17) on project performance as follows.

Planning and Conceptual Design Phases

The operability and maintainability practices that were suggested or reported by the respondents confirm their awareness of the significance of early O&M staff involvement in the planning and conceptual design phases. The data from the case study led to the identification of some principles for the proper implementation of operability and maintainability during these phases. Early involvement of O&M ideas in the planning stage has also been identified as critical for project success in many other studies (Cooper, et al., 2004; Hsu, et al., 2011; Markus & Mao, 2004; Thomke & Vvon Hippel, 2002). Dodin and Elimam (2008), for example, stated that the sequencing of equipment in the project planning and conceptual design phases results in huge trade-offs in costs, and generates practical schedules at the lowest possible cost.

Integration is one of the critical concepts frequently highlighted by the respondents and the literature review in this research. The integration of project users with planners is essential in order to combine their efforts to make the most of project performance (Tesch, et al., 2009). Critically, the project planners and designers can improve their schedules by integrating their work with the real users and operators of a project, because it allows them to gain a better understanding of the potential O&M problems. In addition, it provides a proper condition to identify the project's O&M limitations and capabilities. The case study findings showed that having the O&M ideas as an integral part of the project planning and conceptual design has a significant influence on the project performance (Proposition 1). The examination of the data concluded that the integration concept can be applied through user group sessions, multi-disciplinary consultation sessions or O&M workshops. It prevents many O&M problems, and improves the project time and cost needed for O&M purposes. Integration facilitates the involvement of a mixture of highly experienced managers and technicians during the planning and conceptual design phases, which can significantly provide rich inputs into a project (Proposition 4). Early consideration of O&M team skills in the planning phase enables planners to identify the potential capabilities for O&M, as well as their limitations.

The lack of a standardisation is a central challenge to O&M professionals, and the introduction of standardisation could effectively fix most problems. This approach was regularly supported by a range of respondents from the AMSU, CHRISP, HIDD, RBWH and TH. Further analysis revealed that standardisation of O&M definitions and processes within the planning and conceptual design phases can prevent many O&M problems (Proposition 2), for example, master planning or service planning standardisation processes were suggested by a participant from the AMSU. With O&M standards defined in the guidelines, O&M professionals can operate and maintain projects in a more time and cost-effective manner. This improves the O&M processes even further, specifically if it is performed through interactions of the planners and O&M professionals of a particular project.

An early programming that is based on accurate consultations during the planning or conceptual design phases could also guide projects to be construction- and O&M-sensitive (Proposition 3). When a comprehensive program is provided with enough supports for every single post-occupancy concern, it facilitates a faster progression of governmental funding for the O&M phase of infrastructure projects. By incorporating detailed O&M considerations into programs, the project planners can take advantage of the opportunity to design a more operable and maintainable program.

Detailed Design Phase

An infrastructure project should be designed in detail in order to be fitted to its final use. To achieve that, identification of the clients' expectations for development of the project at the detailed design phase is very important. This is consistent with the approach proposed by Howes and Robinson (2005) who claimed that the design phase should fulfil the needs of both the project contractors and clients. Accordingly, the designers, similar to the planners, should understand what the final project will look like, and what its final purposes are (Frame, 2003). The detailed design phase is undoubtedly the most critical phase of the PLC, because most of the constructive and in-depth decisions for a project are made within this phase. Therefore, data from the interviews and document review in the current study was scrutinised in order to identify some principles for the proper implementation of operability and maintainability in this phase.

In addition to the propositions that were given for the planning and conceptual design phases, which are also closely relevant to the detailed design stage, this research argues that enabling the O&M professionals to have authority at the detailed design stage ensures a cooperative process (Proposition 7), although it is not an easy task. For example, a manager from the HIDD said that there were always strict preventive controls rregarding how the O&M engineers were involved in the design processes. The O&M professionals should have enough authority to test the design sketches (CIMR, 2012j; SAMF, 2010d). The case study revealed that although the O&M respondents were in-principle willing to have such a role in the detailed design phase and to share their knowledge through face-to-face interactions with the designers, they did not actively contribute to this sharing, because the current conditions did not provide enough opportunities for this purpose. For example, the GCUH allowed an O&M manager to enter the construction phase as one of the project managers. This gave him enough authority to make necessary changes during the construction phase based on his O&M experience; however, he reported that there were always plenty of confronting reactions against the changes for him to contend with.

Supporting this argument is the evidence from other participants, suggesting that the engagement of O&M professionals with enough authority in the detailed design phase enhances the operability and maintainability implementation while it improves accessibility, flexibility, cleanability and functionality problems in the design sketches (Propositions 5, 6, 9 and 11). The health projects are usually not flexible and accessible enough to be adapted to new technological advances (Lam, et al., 2010; Lavy & Shohet, 2004; Pintelon & Gelders, 1992; Shen, 1997; Shohet, 2003; Shohet, et al., 2002; Williams & Clark, 1989). Therefore, the failure to consider such problems during the design phase could also explain why the implementation of the operability and maintainability tended to be unsuccessful. This view is supported by Dunson and Williamson (1999) who suggested that a design incorporating functionality and accessibility concerns can increase the expected life-cycle of a project and make the best use of costs.

The findings of the present research agree with Wells (1986) regarding the observation of a large degree of isolation between the designers and technical staff. It is mostly architects who are leading the design teams, and as shared by a manager from CHRISP in the interviews conducted in the present research, architects typically think that they can manage the whole design process, so they do not involve O&M engineers in order to get their technical inputs. Yet technical inputs are among the major determinants for project success (Ashley & Jaselskis, 1987; Pinto & Slevin, 1987). This research concluded that having technical leaders instead of architects in the detailed design phase enhances the implementation of operability and maintainability (Proposition 14). The CIMR guideline also states that the planning and design stakeholders of health facilities need knowledge about the proper relationships between different components (CIMR, 2012e). For this reason, technical leaders can enhance the transfer of O&M knowledge and experience into the design phase, clarifying the different O&M components that should be considered at the early project stage (Proposition 12).

An engineering design can also make considerable savings throughout the PLC. The CIMR guideline points out the significance of engineering designs. The engineering design selects the most appropriate O&M engineering methodology at the design stage so that O&M staff can clearly see the direction in front of them (Proposition 10). Preparation of the CIMR guideline was one of the primary steps in identification of the most appropriate O&M methodologies for QH project designers; however, this research contends that this iteration of the guideline fails to consider the effectiveness and efficiency of the O&M phases in the development of project specifications. Development of project specifications while considering the effectiveness and efficiency of the O&M phases significantly enhances operability and maintainability implementation (Proposition 13). Salleh (2009) echoes that adequacy of specifications is one of the major success factors in infrastructure projects. Additionally, this research argues that the selection of proper methodologies or technologies for the O&M phases should be based on the available skills and resources (Proposition 8). The design drafts that do not consider the availability of the O&M skills and resources can easily create difficulties for O&M professionals, because it is the responsibility of O&M engineers to later supply the necessary equipment, materials or skills during the post-occupancy stage.

Construction Phase

Having O&M staff with enough power to affect the construction phase is as significant as having them involved in the detailed design phase, because involvement in both phases is necessary in order to enhance the operability and maintainability processes (Proposition 7). In contrast to this view, a maintenance manager from TH argued that giving authority to O&M staff in the construction phase did not necessarily help; instead, employing experienced staff as the operability or maintainability reviewers might be a better option. This was because busy O&M professionals did not have enough time to spend giving advice and making inputs into the design or construction of other projects, which is so time-consuming. In the GCUH project, for example, an experienced maintenance manager was employed in the site management office, both to make inputs into the construction stage and check the handover process of documents and manuals. The distribution of documents and manuals before the training also facilitates an easier start for O&M staff and enables them to make the best use of the facilities' liability period (Proposition 15).

O&M Phase

This study concluded that although early consideration of the O&M problems saves a significant amount of post-construction cost and time, it does not still replace the effectiveness and efficiency of using innovative techniques and methods during the O&M phase of infrastructure projects (Proposition 16). Use of innovative maintenance techniques or maintenance management methods was among the strategies suggested by the respondents. This is also supported by the CIMR guideline which indicates that the use of new technologies for O&M purposes should be maximised in parallel with the new technologies in medical equipments.

Further analysis also showed that obtaining periodical feedback from the O&M professionals in the long-term potentially helps to identify liability period problems and improves operability and maintainability implementation in future projects (Proposition 17). Periodic feedback gives a real picture of how the designs work in the O&M stage and tests the actual behaviour of the services and facilities in the longer term. This provides a better understanding of what to expect for future projects and how to manage the ideas taken from the feedback to improve the designs and construction techniques. The feedback capability is an important factor affecting infrastructure project success (Belout, 1998; Chua, et al., 1999; Hubbard, 1990; Jaselskis & Ashley, 1991; Walker & Vines, 2000). This is supported by Pinto and Slevin (1987) who stated that regular monitoring and feedback can lead projects to success.

It is apparent that the construction contractors often run out of time to handover the project to the clients. This leaves the O&M staff little time to develop and participate in training. It is also obvious that the liability periods of facilities and services have already started when the project is delivered. Feedback mechanisms can easily show how much pressure the O&M staff are facing. Meanwhile, the staff need to handle training, carry out the O&M responsibilities, pay attention to the liability period of the services and facilities, and seek compensation for the problems in the devices and equipment.

Overall, these findings indicated a variety of impacts of the O&M integration into the early PLC phases on the enhancement of operability and maintainability implementation. Building on the identification of these impacts, this research shows how the combination of the currently implemented operability and maintainability strategies with the constructability principles provides a comprehensive model that prevents the isolation of different project phases from each other. The next section concludes this chapter by providing an overview of this final model.

7.4 CONSTRUCTION, OPERATION AND MAINTENANCE ABILITY MODEL

The research reported in this thesis examined the way that early involvement of O&M concerns in the planning, design and even construction phases influences the effectiveness and efficiency of operability and maintainability implementation in health infrastructure projects. This research also indicated that the integration of different project phases is a major indicator of project success (Cooper, et al., 2004; Hsu, et al., 2011; Markus & Mao, 2004; Tesch, et al., 2009; Thomke & Vvon Hippel, 2002), which is a complex subject affected by different factors that arise during the PLC phases. To achieve the proper integration of O&M concerns into the early project phases, 17 operability and maintainability principles were identified as discussed in Chapter 6. The derived 17 operability and maintainability principles involve early decision-making processes for O&M activities within the planning and design phases. In a similar vein, the discussion in Chapter 3 (Section 3.2) showed that the 12 CIIA constructability principles decrease PLC costs through early decision-making processes for construction activities within the planning and design phases. The CIIA constructability principles are considered as the basis for the model development purposes, because they have been extensively researched, practised, and developed in the construction industry, compared with the concepts of operability and maintainability.

To develop the extended CIIA constructability model, namely, the Construction, Operation and Maintenance Ability Model, as the final output of this research project, the researcher kept the CIIA constructability principles as the foundation; then, the currently identified operability and maintainability principles were added to it. During the extension process, some of the principles which had close definitions in both the CIIA constructability model and the COM Ability Model were merged together. They included ‘integration’, ‘program’, ‘team skills’, ‘available resources’, ‘methodology’, ‘knowledge’, ‘specifications’, ‘ innovation’, ‘accessibility’, and ‘feedback’. For example, ‘integration’ in the CIIA constructability model emphasised the need to make constructability the integral part of the project plan, while it highlighted the need to make the process of early involvement of O&M staff (operability and maintainability) as the integral part of the project plan in the designed operability and maintainability model. The same strategy to merge the principles with close definitions was implemented during the extension process. These principles are shown in the first column of Table 6. These principles were then verified using another round of interviews with different project stakeholders. The results taken from the verification process are also summarised in the second column of the table. The third column highlights the practical implications of each principle; these implications are generally related to increasing post-construction awareness and ensuring the effective and efficient early involvement of O&M professionals in the early PLC phases, as well as construction contractors.

Table 6. Verification and practical implications for COM ability model principles sharing close definitions with CIIA constructability principles

No.	Principles	Verification (2nd Round of Interviews)	Recommendations and Practical Implications
P1	Integration	This research suggests that integration of the PLC ideas at the early project stage is an effective idea; however, there was sometimes some resistance from planners and designers. From the point of view of the respondents the integration idea is critical in how they sort out multi-faceted infrastructure projects.	• It is recommended that the infrastructure project owners to be aware of integration of ideas to enhance implementation of COM phases. • This study also implies that application of different techniques for better integration should be supportive and participative.
P3	Program	The findings suggest that the overall program of infrastructure projects should be realistic and COM-sensitive; however, the programs proposed by politicians are mostly fixed to a certain period of time that makes dealing with any changes in the plan very difficult.	• It is suggested that programs for infrastructure projects should be prepared in detail before politicians allocate the budget to the projects. This gives a better understanding of real COM costs to the politicians, and prevents probable underestimations.
P4	Team Skills	The experts are those who should provide advice regarding the whole project in peer review sessions by using their skills. Some respondents believed that many experts with relevant skills were outsourced from health projects, and as a result, project owners were faced with a lack of team skills and expertise.	• To ensure a complete experienced COM team for the project, it is recommended to check the availability of different skills and expertise required for COM phases as early as possible. • Due to the shortage of some specific skills in some small cities, it is recommended to construct (or rent) accommodation on the construction site or near the construction area, and provide a good living situation to attract professional staff from other cities.
P5	Accessibility	The respondents confirmed that the concept of accessibility is significantly important in health projects (for example, service tunnels), particularly when access paths are made separately. It should also be considered that access paths may even need to change every few years.	• This research suggests the design of separated access paths for the O&M staff to avoid disturbance for patients or other professional staff like nurses, doctors and visitors in the infrastructure project. • Due to fast changes in multi-faceted health projects, the design and construction of access paths should be change-ready.
P8	Available Resources	The availability of resources, including both equipment and skilled people, is a very important issue specially outside the big cities. For example, designers of the Hamilton Island Hospital accommodated all the building staff into the resort, because they had	• It is recommended that the designers of infrastructure projects be actively aware of the availability of resources in COM phases. • Caring about availability of resources, such as equipment, services or skills, can avoid

(Cont'd)

No.	Principles	Verification (2nd Round of Interviews)	Recommendations and Practical Implications
		difficulty in finding enough local skilled staff. The 2nd round of interviews suggested that the availability of resources should always be considered when planning and designing the infrastructure projects.	unwanted stoppages during COM of infrastructure projects.
P10	Engineering Methodology	This research suggests that projects with cheap construction methods often cost more to run and maintain. Sometimes it is better to spend more to bring COM staff into the planning and design phases to have a cost-effective engineering design. This has always been a struggle as initial engineering design costs and PLC costs do not usually complement each other.	• To have a cost-effective engineering design, infrastructure project owners should: ✓ set the contract in a way that the designers are obliged to collect ideas from a wide range of COM staff in order to consider all engineering aspects of the COM phases. ✓ ensure that although considering the engineering methodology in the design process may increase the design cost, the total PLC cost will significantly decrease.
P12	Knowledge	The verification process confirmed that early consideration of COM knowledge during the planning or design phases prevents unwanted waste of time and costs. The current practices based on constructability principles bring construction knowledge into the early project stages, although there is still a significant need to incorporate it with the operability and maintainability considerations to include the O&M phases.	• Where possible, it is useful to facilitate proper interactions by providing open designed areas and plans where the COM staff can freely exchange their valuable knowledge with the project owners and planners.
P13	Specifications	This research confirmed that proper identification of project specifications, such as correct locationing of the site, weather conditions, and distance from sea or river etc, directly impacts on the efficiency of the COM phases.	• Infrastructure project planners and designers should define detailed specifications of the project at the early planning and design stages to avoid impracticality of plans and sketches, and create an atmosphere in line with design specifications for purpose matching not disparity.
P16	Innovation & Consistent Computerisation	The verification process revealed that use of innovation does not necessarily save time and money in COM of projects, so relying on old methods is sometimes better. The innovation may even cause additional costs in the long-term. The innovation can result in	• This study recommends that absorption of proper new COM technologies could potentially save a lot of time and money in constructing, operating or maintaining the health infrastructure projects by encouraging the use of innovation

(Cont'd)

No.	Principles	Verification (2nd Round of Interviews)	Recommendations and Practical Implications
		savings, if it is followed by proper technology absorption. For this reason, a new name is assigned for this principle: 'technology absorption'.	and computerisation in tools, equipment, and COM management softwares.
P17	Feedback	Projects are normally handed over very late. The warranties are also usually for 12 months, so by the time the project is completely handed over, O&M staff have already missed about half of the warranty period. As a result, they have not used the services and equipment long enough to identify their problems. Reviews of O&M performance and feedback feed the next projects if reviews are continuously performed over different project stages, not only within the initial 12 months of warranty.	• Getting long-term feedback from the O&M stakeholders gives them enough time to see the real problems with services, equipment and facilities, and enhances their collaborative ideas for future projects. • It is also recommended that such long-term feedback can help the designers to realise the importance of early consideration of such ideas from past projects in operability and maintainability implementation for future projects.

During the extension process, it was also noted that there are some other principles among the identified operability and maintainability principles that bring completely new ideas into light, which were not within the scope of the CIIA constructability model. For this reason, these principles were considered as new principles for the COM Ability Model. They include 'standards definition', 'adaptability/flexibility', 'authority', 'cleanability', 'functionality/fit for purpose', 'technical leaders', and 'handover of documents'. For instance, 'functionality/fit for purpose' is a principle that focuses on the need to have flexible/adaptable designs to help to ease modifications/retrofits while operating or maintaining multi-faceted infrastructure projects; however, no similar principle to this one existed in the CIIA constructability model. These principles are shown in the first column of Table 7. Similar to the previous table, the second column of the table presents the verification process of each principle, and the third column highlights the practical implications of each principle.

Table 7. Verification and practical implications for COM ability model principles with completely new ideas

No.	Principles	Verification (2nd Round of Interview)	Recommendations and Practical Implications
P2	Standards Definition	This research observed that when the minimum COM experience was properly analysed and brought into the guidelines or standards, it would be an advantage, although there has always been a debate on what ‘minimum’ means. A construction contractor argued that there is not usually evidence of such standardisation in current health projects.	• This research suggests that it is necessary to provide a framework clarifying what the minimum expectations from standardisation are in every single project. When the minimum expectations are well defined in standards or guidelines, project stakeholders will find out to what extent they are expected to share their knowledge, skills and experience at the early project stage.
P6	Adaptability/ Flexibility	An adaptable/flexible design is likely to provide a significant advantage for COM stakeholders in covering and future-proofing whole PLC. As the contemporary designs of infrastructure projects do not automatically match their future needs, the concept of adaptability/flexibility is receiving a lot of attention. The adaptability/flexibility should be implemented in the right form, vein and department, although the project owners do not necessarily achieve the ultimate adaptability/flexibility.	• A flexible/adaptable design easily matches with future changes and modifications in infrastructure projects. A future-proof project is compatible with sudden adjustments and prevents project lock-ups or work stoppages. • The use of flexible materials and services is highly recommended for COM of infrastructure projects. Removal, repair, or adjustment of such flexible materials and services is much cheaper and faster.
P7	Authority	Authority is the ‘ability to endorse’ which should not necessarily be given to a single person as representative of all; however, it should be spread through involvement of all the key staff. ‘Roles and responsibilities’ of the COM staff should be clarified to the planning and design teams. ‘Delegation’ is a better name for this principle as it elaborates its uniqueness much better. Another respondent stated that if you give authority to anyone, he/she will drive too much in that direction, so it is better to place the COM staff as ‘influence makers’ which balances the power at the early project stage.	• It is recommended that allocating delegation to the COM professionals at the early PLC phases should be continuous and properly organised. • The identification of roles and responsibilities for the COM professionals at the early PLC phases supports the collaborative climate and helps the COM professionals recognise they are not disregarded, but involved as part of a supportive team.
P9	Cleanability	Cleanability in health projects is significantly vital; however it is better described as ‘cleanability and infection control’. Discussion on infection control issues, such as the fabric of facilities, is a major part of the detailed design phase in health	• To ensure greater cleanability of Complehealth projects, it is highly recommended to provide meetings between designers and the real future cleaners to introduce an easily cleanable project.

(Cont'd)

No.	Principles	Verification (2nd Round of Interview)	Recommendations and Practical Implications
		infrastructure projects.	• Due to literacy/communication problems of many project cleaners, it is recommended to develop a clear consultation plan with clear timing to achieve this purpose.
P11	Functionality/ Fit for Purpose	This research observed that although the designs should be fitted for purpose, there is always debate on how to sit the fit for purpose concept. Perceptions of hospital operating and maintaining staff about project purposes are certainly different from designers. For this reason, it is very important to get to a single or similar definition for functionality/fit for purpose at the early project phases of planning or design.	• It is recommended that project purposes should be discussed and clarified among different project stakeholders. This facilitates an environment, such as user group sessions or multi-disciplinary consultation sessions, that lets the participants share their perception of fit for purpose/ functional project.
P14	Technical Leaders	Although some architects are experienced enough, even in technical aspects of health projects, it is still a good idea to have technical skilled managers as the leaders of the planning and design teams, instead of architects. This facilitates a more cost-effective technically designed project.	• Having technical people as the active leaders of the design teams improves technological/mechanical aspects of design sketches. The designers are mostly dispersed from the technical side of COM phases in multi-faceted infrastructure projects, so a technical leader can encourage the design team members to consider the technical aspects in addition to architectural considerations.
P15	Handover of Documents	Many respondents believed that handover of documents is a very important principle in the COM Ability Model. Moreover, they stated that it is better to name it 'handover and training' as training is always a major part of the handover stage. The training enables the O&M staff to recognise problems of project facilities, services and equipments beforehand. In addition, inspections during and after the construction phase prevent poor construction techniques. In brief, handover fulfils the building readiness specification, while training focuses on service readiness of the project.	• Preferably, the infrastructure project owner should consider assigning the O&M personnel with pre-defined responsibilities to ensure more effective operability and maintainability implementation. This may include: ✓ checking the handover documentations. ✓ providing experience and advice for the project contractors. ✓ organising workshops or trainings. ✓ guiding preparation of the manuals.

Two principles, namely, 'external factors' and 'corporate objectives', were among the CIIA constructability principles, but were outside the concern of O&M staff and were not among the operability and maintainability principles. These principles were still kept in the COM Ability Model exactly the same as they were in the CIIA constructability model, because their significant impacts on enhancement of the construction activities cannot be neglected. These two principles are presented in the first column of Table 8, including their verification process in the second column, and their practical implications in the third column.

Table 8. Verification and practical implications for COM ability model principles of 'external factors' and 'corporate objectives'

No.	Principles	Verification (2nd Round of Interview)	Recommendations and Practical Implications
P18	Corporate Objectives	Getting to know the corporate objectives of clients results in better COM implementation. It provides a more similar point of view between the planners, designers, contractors, O&M staff and clients.	• Where possible, it is useful to clarify the corporate objectives of the project to the designers, in addition to project objectives. This can take place through face-to-face interaction of the designers and corporate staff at the earliest possible time of project definition. It brings different points of view together and results in consistency in design process.
P19	External Factors	This research suggests that external factors significantly affect the project COM performance. For example there are always some political, financial or economic issues that affect the project progress. Prices change regularly and there are always some unexpected inflations.	• In order to enhance conditions for COM performance, infrastructure project owners should: ✓ be aware of different aspects of probable external factors such as political, financial or economic issues, aiming to prevent unexpected extra budget or time needed for the COM of the project. ✓ make appropriate preventive decisions accordingly.

As a result of this extension process, 19 principles are proposed for the COM Ability Model which are a mix of the CIIA constructability principles and the operability and maintainability principles identified in the present research. These principles are outlined in Table 9. As expected, most of the principles are relevant to the planning and conceptual/detailed design phases, while some principles are relevant to the construction stage, and a few principles are relevant to the O&M stages. The COM Ability Model principles target one single goal, which is to enhance the integration of different project phases in order to facilitate the successful delivery of infrastructure projects. By applying these principles, it is anticipated that the performance of the COM of infrastructure projects will continue to be enhanced. Each principle aims to facilitate an environment for easier integration of ideas among different project phases. The principles are designed in such a way that each focuses on a specific aspect of incorporating ideas from later phases to earlier steps, and their combination in such a comprehensive model covers all the concerns of the interviewees and reviewed documents.

Table 9. COM ability model

COM Ability Principles	**Typical PLC**			
	Planning	**Conceptual and Detailed Design**	**Construction**	**O&M**
P1. Integration	Relevant	Relevant	Moderately Relevant	Moderately Relevant
P2. Standard definition	Relevant	Moderately Relevant	Not Relevant	Not Relevant
P3. Program	Relevant	Relevant	Moderately Relevant	Not Relevant
P4. Team skills	Relevant	Relevant	Not Relevant	Not Relevant
P5. Accessibility	Not Relevant	Relevant	Moderately Relevant	Not Relevant
P6. Adaptability/Flexibility	Not Relevant	Relevant	Moderately Relevant	Not Relevant
P7. Technical leaders	Not Relevant	Relevant	Not Relevant	Not Relevant
P8. Available resources	Relevant	Relevant	Not Relevant	Not Relevant
P9. Cleanability	Not Relevant	Relevant	Moderately Relevant	Not Relevant
P10. Engineering methodology	Moderately Relevant	Relevant	Moderately Relevant	Not Relevant
P11. Functionality/Fit for purpose	Not Relevant	Relevant	Moderately Relevant	Not Relevant
P12. Knowledge	Moderately Relevant	Relevant	Moderately Relevant	Not Relevant
P13. Specifications	Not Relevant	Relevant	Not Relevant	Not Relevant
P14. Delegation (Authority)	Moderately Relevant	Relevant	Relevant	Not Relevant
P15. Handover and trainings	Not Relevant	Not Relevant	Relevant	Moderately Relevant
P16. Feedback	Not Relevant	Not Relevant	Not Relevant	Relevant
P17. Technology absorption	Not Relevant	Not Relevant	Relevant	Relevant
P18. Corporate objectives	Relevant	Relevant	Not Relevant	Not Relevant
P19. External Factors	Relevant	Relevant	Not Relevant	Not Relevant

Legend: Relevant   Moderately Relevant   Not Relevant

The COM Ability Model principles look at all the PLC needs from a very broad viewpoint. They are not designed for a specific project phase, but cover the whole PLC. In terms of use, the on-time implementation of these principles plays a significant role in achieving highest project outcomes. Project owners must set out the contract in such a way that all the project stakeholders are obliged to read, understand and implement each principle from the early planning to post-construction stage. Project planners and designers are also responsible to create an environment that lets the construction and post-construction professionals enter earlier project phases to transfer their experience and skills. In addition, O&M professionals must allocate a part of their daily practices to make proper inputs into the multi-disciplinary consultation or user group sessions, using the above principles.

Many respondents provided positive feedback about the COM Ability Model. One manager from HIDD said:

> "I think what you have done (in this model) is very broad. It is fantastic." [HIDD]

A maintenance manager from RBWH echoed a similar viewpoint:

> "I think your model is overall, but comprehensive. It captures the basics on what you need to do." [RBHW]

In terms of naming this model, an engineer from a contractor company stated:

> "The 'COM Ability Model' is a good name. It is like an abbreviation of different names. You have shortened it. It is a very good naming!" [AEROCON]

An architect from the GCUH project also said:

> "I think selection of 'COM Ability Model' was a great idea for it." [GCUH]

7.5 SUMMARY

The aim of this research was to improve the effectiveness and efficiency of operability and maintainability of infrastructure projects by extending the constructability concept to include O&M phases. This chapter created the bridge to reach the research conclusions through assessment of the findings and elaboration of the practical implications. The next chapter concludes this study and presents the overall implications for academics and practitioners, recommendations for future studies and closing comments.

Chapter 8: Conclusion

8.1 INTRODUCTION

This study attempted to extend the concept of constructability to include O&M phases, in a model named as the COM Ability Model. This was done through the use of the case study research method. It provided a better understanding of the complexity of O&M concerns in infrastructure projects.

Chapter 7 proposed practical implications for each COM Ability Model principle to improve the effectiveness and efficiency of the constructability, operability and maintainability of health infrastructure projects. The overall findings from this chapter also show that isolating planners and designers from the construction and O&M knowledge creates a barrier to optimum project delivery. To avoid such separation, the COM Ability Model looks at both the pre- and post-occupancy stages together and this facilitates the integration of ideas. The discussion in this chapter also elaborates on a number of contributions that will be of benefit to academics and practitioners.

Through a summary of the findings, this chapter will provide answers to the main research question, highlight the contributions that will be of benefit to academics and practitioners, and offer some recommendations for future study.

8.2 INTEGRATION OF CONSTRUCTABILITY, OPERABILITY AND MAINTAINABILITY

Constructability, operability and maintainability are the concepts that integrate different project phases with each other; however, their isolation from each other has caused a range of problems for the successful delivery of infrastructure projects. The concept of constructability was considered as the basis for the extension purposes, because it is much more popular, practised and developed compared with the other two concepts in both the international and Australian construction industry. For this reason, this study identified different problems and limitations for the proper integration of O&M inputs into the planning and design phases. Despite these limitations, current operability and maintainability practices are already having positive impacts on the delivery of infrastructure projects. For this reason, the present research extended the existing CIIA constructability principles to include the identified operability and maintainability principles in the proposed COM Ability Model. This section shows how the COM Ability Model principles can assist in facilitating the successful delivery of infrastructure projects through strengthening the practice of integration between different project phases.

The main focus of this research was on improvement of the concepts of operability and maintainability. Identification of problems faced during the O&M phases of the PLC and the practices that have been used in addressing those problems have provided an understanding about how to best deal with those problems, in particular in the earlier phases of the PLC. It has been shown that to improve the effectiveness and efficiency of operability and maintainability in multi-faceted infrastructure projects, the following strategies need to be considered:

- Make O&M another important discipline in the pre-occupancy stage, specially in early project planning and design, exactly the same as the concept of constructability currently does for construction.
- Set out the contract in such a way that planners, designers and even construction contractors are obliged to collect ideas from a wide range of O&M professionals in order to achieve a complete and comprehensive engineering design.
- Conduct training for all project stakeholders in order for them to learn how to implement operability and maintainability.
- Provide an environment for O&M professionals to participate in multi-disciplinary consultations or user group sessions, and let them share their perceptions of a real functional project.
- Collect continuous feedback from O&M personnel in the long-term.
- Apply particular COM Ability Model principles, which have been particularly developed based on data collected on Australian health infrastructure projects.

The operability and maintainability principles which were used for extension of the CIIA constructability model, in the COM Ability Model, have also taken various points into account in order to provide some key strategies on how to best enhance the involvement of O&M professionals in the early PLC phases. These strategies are summarised as follows:

- Identification of the roles, responsibilities, and minimum expectations from every single COM stakeholder in the guidelines or standards.
- Preparation of the project program before allocation of the budget by politicians.
- Planning and design for the right project specifications based on the availability of skills, expertise, experience, and other necessary resources.
- Design and construction for a change-ready and future-proofed project by using safe and flexible/adaptable materials, equipment and services.
- Improvement of both the communication and professional skills of O&M personnel by conducting workshops and training as early as possible.
- Having O&M professionals check the handover process and guide the preparation of the manuals.
- Allocation of technical leaders for the design teams.
- Technology absorption and computerisation in tools, equipment, services and management strategies.
- Categorisation of external factors that may negatively affect the planning and design phases.

8.3 CONTRIBUTION OF THE RESEARCH TO ACADEMICS AND PRACTITIONERS

This research project produced an extended constructability model to improve the successful delivery of infrastructure projects by taking the O&M concerns into consideration. It integrates the ideas taken from different project phases and brings the post-occupancy concerns to the early phases of infrastructure projects. The findings from this study make a number of contributions that should be of benefit to academics and practitioners. This section elaborates on each category of contribution separately.

Contribution to Academic Field

This research makes a number of contributions to the academic domain. In brief, this research:

(1) provides a deeper academic understanding of the concepts of constructability, operability and maintainability particularly with regard to implementation of its principles in multi-faceted infrastructure projects.

(2) facilitates a wider range of coverage for CIIA constructability principles which contributes to an extended model that is ready for use in different infrastructure projects.

(3) brings the concepts of operability and maintainability to broader attention for future research projects through constructing the operability and maintainability principles.

(4) presents new or extended principles in the COM Ability Model that provide a better understanding of the influences of early decision-making processes to reduce O&M problems in infrastructure projects.

(5) broadens the practicality of the concept of constructability for future studies, although it still keeps its initial framework.

Contribution to Practice

This research also offers a number of practical implications, as detailed in Chapter 7 (see Table 6). Overall, this research:

(1) gives emphasis to the awareness of infrastructure project stakeholders regarding the early determination and evaluation of O&M concerns during the PLC.

(2) provides managers a supportive guideline on how to improve the operability and maintainability of infrastructure projects through early integration processes.

(3) presents insights into the implementation of operability and maintainability.

(4) lists a series of current practices performed to address O&M problems, which creates an efficient platform for further research.

(5) integrates all the PLC phases so that project planners and designers can have a better understanding of O&M problems.

(6) provides a guideline that results in more constructible, operable and maintainable infrastructure projects.

(7) provides a guideline that eliminates/reduces project reworks during O&M phases and, consequently, significant savings in the whole PLC costs are expected.

(8) provides a foundation for further involvement of the O&M staff in earlier project phases; consequently, major savings in the whole PLC cost are expected.

In the short-term, it is suggested that the O&M stakeholders use the existing list of current practices (shown in Chapter 5) to evaluate the dominant influence that they can have on the prevention of O&M problems. However, the main intention for doing this research was to explore the long-term influence of using the COM Ability Model in multi-faceted infrastructure projects. It is recommended that all project stakeholders should be encouraged to consider the use of the COM Ability Model principles as a collaborative tool to enhance integration. Although achieving an ideal stage may be time-consuming, the use of such principles can result in projects with higher values and fewer O&M problems.

8.4 LIMITATIONS AND FUTURE RESEARCH

It is important for each research project to acknowledge its limitations so that the context of the findings can be clarified for the readers, and the limitations can serve as indicators for future studies (Too, 2009). There are certain limitations in this study and these are briefly listed as follows:

- A case study approach is successful when all the participants have the willingness to share their experience without any bias during the data collection stage. The first round of interviews in this study was with the O&M professionals who were among the very busy operating staff in health projects. For this reason, it was difficult to organise long interviews with them, and the interviews did not give them much time to share their full understanding of the research problem. The second round of interviews also had the same limitation as the interviews were conducted among top senior management staff. To address such a limitation, a review of the documents as another method of data collection was added to this research in order to support the viewpoints of the participants, and decrease the bias.

- An important rationale for conducting this study was the capability for expansion of the final extended model to be used for other types of projects, beyond only health projects. Due to the limitation of time for data collection and analysis in this research project, the main focus of this study was to draw out the core principles for enhancing the integration of COM staff in earlier project phases of health projects only. This was also narrowed to the viewpoints of some selected staff from the district and corporate sections of the Queensland Health Department, thereby limiting the prosperity of the collected data. Nevertheless, the verification process expanded the circle of respondents to a wider range of project stakeholders who had been involved in other types of infrastructure projects as well. This provided more comprehensive principles that can be investigated further in future studies in order to be completely compatible with other specific types of infrastructure projects.
- The researcher was the only person who collected and analysed the data. This may have brought some bias into the data. However, the use of NVivo software for data analysis purposes, the use of a document review method as another method of data collection, and verification of the final extended model through another round of interviews with a different group of professionals in the field, as recommended by Sackmann (1991) and Eisenhardt and Bourgeois (1988), decreased the existing bias.

Although this research provided some valuable insights into the problem of the lack of integration between the concepts of constructability, operability and maintainability, further explorations are still required to simplify the existing complex problem. As suggested by Eisenhardt and Graebner (2007), such research findings can serve as hypotheses for future studies; in this case, the findings can service as hypothesis for future studies into the concept of integration in different types of projects. The above-mentioned limitations of the research suggest some recommendations for future studies as follows:

- The main focus of this research was on health infrastructure projects. It is recommended that future studies use the outcomes of this research as the basis for further expansion of the COM Ability Model to be compatible with other types of infrastructure projects.
- The COM Ability Model is designed based on the data collected from some selected cases in Queensland. Due to the uniqueness of the concepts of constructability, operability and maintainability, the COM Ability Model which is an integration of these three concepts also needs specific tests in order to be used in other locations. Future studies may carry out implementing testing.
- The interviews show that the type of contract used in every single project can have a significant influence on how well the ideas of the project stakeholders can be integrated into the different project phases. For this reason, it is recommended that future studies focus on the impacts of the contract types on improvement of the COM Ability Model.
- The literacy and communication problem of many O&M staff was identified as one of the major barriers to the proper implementation of the operability and maintainability in health infrastructure projects. It is important to have personnel who can transfer their knowledge and experience into the early PLC phases. Future research work may include a more detailed study into how to improve the communication problems of O&M professionals in health infrastructure projects and set the standards to enhance the requirements.

The next section, as the final section of this chapter and thesis, concludes the information given, and highlights some closing comments.

8.5 CLOSING COMMENTS

Overall, this research has shed light on successful project delivery through the integration of constructability, operability and maintainability. It demonstrated the diverse practices implemented in the O&M of health infrastructure projects to address existing problems. To address these O&M problems, all infrastructure project stakeholders must assist in developing proper principles aimed at providing an easier early integration of O&M ideas with the planning and design phases. This research identified the operability and maintainability principles relevant to each project phase separately, and then used CIIA constructability principles as the platform for extension purposes. It is clear that every principle of the final model has diverse impacts on the effective and efficient implementation of COM. The COM Ability Model, as an improved and extended structure for the concept of constructability, will make infrastructure project owners more aware of the significance and function of early integration in contributing to successful project delivery.

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Appendices

Appendix A
Participant Information Sheet and Consent Form for Semi-Structured Interviews

Queensland University of Technology
Brisbane Australia

PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT

Extension of Constructability to Include Operation and Maintenance for Health Infrastructure Projects

QUT Approval Number 1100001558

RESEARCH TEAM

Principal Researcher:	Ehsan Saghatforoush, PhD Candidate, QUT	04 3239 7900	e.saghatforoush@qut.edu.au
Associate Researchers:	Bambang Trigunarsyah, Assoc Prof, QUT	07 3138 8303	bambang.trigunarsyah@qut.edu.au
	Eric Too, Lecturer, QUT	07 3138 9257	e.too@qut.edu.au

DESCRIPTION

This research is being undertaken as part of a PhD research.

The purpose of this research is to explore the concept of constructability to improve the effectiveness and efficiency of conceptual planning and design phases of health infrastructure projects. Specifically, it will consider how the operation and maintenance stakeholders can be engaged in the planning and design stage to ensure the successful delivery of health infrastructure projects. The outcome of this research is an extended constructability model that will include operation and maintenance considerations. Through comprehensive testing with project stakeholders within the health infrastructures, this extended model can serve as guidance for practitioners to reduce incompatibilities between the planning, design, construction, operation and maintenance phases of the infrastructure lifecycle.

The research team requests your assistance to participate in this research project by sharing with us your experience of involvement in conceptual planning and design phases of your organisation.

PARTICIPATION

Your participation in this project is entirely voluntary. If you do agree to participate, you can withdraw from the project without comment or penalty. Your decision to participate, or not participate, will in no way impact upon your current or future relationship with QUT.

Your participation will involve interviews and if possible, it may include some site observation and/or review of documents/reports/brochures. The interview will be conducted face-to-face at your office at a time convenient to you. The interviewees will comprise senior managers and other functional managers who are directly involved in the operation and maintenance management of health infrastructure project. The interview should take about 45 minutes each.

EXPECTED BENEFITS

The benefit envisaged from this research is an extended constructability model that can guide practitioners in developing a health infrastructure project that will consider not only construction but also the operation and maintenance issues. This can result in significant reductions in reworks, decreased cost and material waste, and successful delivery of health infrastructure projects. It also results in health infrastructure projects which are more operable and maintainable; consequently it causes a faster and more economical operation and maintenance implementation.

The findings of this research will be shared with the interested participants in the form of a report.

RISKS

There are no risks beyond normal day-to-day living associated with your participation in this project.

PRIVACY AND CONFIDENTIALITY

All comments and responses will be treated confidentially and will be made anonymous when transcribed.

A digital recorder will be used to record the interview. A transcript of the interview will be sent to interviewee for verification. The recordings will be destroyed at the end of the project.

CONSENT TO PARTICIPATE

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

QUESTIONS / FURTHER INFORMATION ABOUT THE PROJECT

If you require any further information about the project, please contact one of the research team members named above.

CONCERNS / COMPLAINTS REGARDING THE CONDUCT OF THE PROJECT

QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Unit on 3138 5123 or email ethicscontact@qut.edu.au. The QUT Research Ethics Unit is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

Thank you for helping with this research project. Please keep this sheet for your information.

QUT Queensland University of Technology Brisbane Australia	CONSENT FORM FOR QUT RESEARCH PROJECT

Extension of Constructability to Include Operation and Maintenance for Health Infrastructure Projects

QUT Approval Number 1100001558

RESEARCH TEAM CONTACTS

Principal Researcher:	Ehsan Saghatforoush, PhD Candidate, QUT	04 3239 7900	e.saghatforoush@qut.edu.au
Associate Researchers:	Bambang Trigunarsyah, Assoc Prof, QUT	07 3138 8303	bambang.trigunarsyah@qut.edu.au
	Eric Too, Lecturer, QUT	07 3138 9257	e.too@qut.edu.au

STATEMENT OF CONSENT

By signing below, you are indicating that you:

- have read and understood the information document regarding this project
- have had any questions answered to your satisfaction
- understand that if you have any additional questions you can contact the research team
- understand that you are free to withdraw at any time, without comment or penalty
- understand that you can contact the Research Ethics Unit on 3138 5123 or email ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project
- understand that the project will include audio-recording
- agree to participate in the project

Name ______________________________

Signature ______________________________

Date ______________________________

Please send this Consent Form to:

Email:
e.saghatforoush@qut.edu.au

Ehsan Saghatforoush
School of Urban Development
Queensland University of Technology
2 George Street
GPO Box 2434
Brisbane QLD 4001

Appendix B
Semi-Structured Interview Questions

<u>To Identify O&M Issues:</u>

1. What are the issues you encounter during Operation and Maintenance (O&M) phases?

<u>To Address O&M Issues / To Identify the Principles:</u>

2. How do you address these issues?
3. Do you use any specific approach to face these issues?

Current Approache

4. What are the difficulties faced in carrying out this approach? → Difficulties

5. Do you foresee any alternative way for it?
6. On what basis do you recommend it?
7. How can this approach confront these issues?

Potential Approache

<u>To Consider O&M Issues in Planning and Design Phases:</u>

8. Can these approaches be achieved by feeding the O&M info into planning and design phases?
9. Who should be involved in planning and design? (You or anyone else?)
10. How can such involvement in planning and design satisfy these approaches?
11. To what extend can such involvement cause achievement of these approaches?
12. How can such involvement in planning and design phases be facilitated?
13. What do you reckon are the benefits of this involvement?

Appendix C
Participant Information Sheet and Consent Form for Fully-Structured Interviews

QUT Queensland University of Technology Brisbane Australia

PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT

Extension of Constructability to Include Operation and Maintenance for Health Infrastructure Projects

QUT Approval Number 1100001558

RESEARCH TEAM

Principal Researcher:	Ehsan Saghatforoush, PhD Candidate, QUT	0432 397 900	e.saghatforoush@qut.edu.au
Associate Researchers:	Bambang Trigunarsyah, Assoc Prof, QUT		bambang.trigunarsyah@qut.edu.au
	Paul Xia, Lecturer, QUT		paul.xia@qut.edu.au
	Eric Too, Lecturer, USQ		eric.too@usq.edu.au

DESCRIPTION

This research is being undertaken as part of a PhD research.

The purpose of this research is to explore the concept of constructability to improve the effectiveness and efficiency of conceptual planning and design phases of health infrastructure projects. Specifically, it will consider how the operation and maintenance stakeholders can be engaged in the planning and design stages to ensure the successful delivery of health infrastructure projects. The outcome of this research is an extended constructability model that will include operation and maintenance considerations. Through comprehensive testing with different project stakeholders within the health infrastructures, this extended model can serve as guidance for practitioners to reduce incompatibilities between the planning, design, construction, operation and maintenance phases of the infrastructure lifecycle.

The research team requests your assistance to participate in this research project by sharing with us your comments on the designed extended constructability model, which now considers operation and maintenance concerns.

PARTICIPATION

Your participation in this project is entirely voluntary. If you do agree to participate, you can withdraw from the project without comment or penalty. Your decision to participate, or not participate, will in no way impact upon your current or future relationship with QUT.

Your participation will involve an interview session. The meeting session will be conducted on a date and place convenient for everyone. The meeting session should take less than an hour.

EXPECTED BENEFITS

The benefit envisaged from this research is an extended constructability model that can guide practitioners in developing a health infrastructure project that will consider not only construction but also the operation and maintenance issues. This can result in significant reductions in reworks, decreased cost and material waste, and successful delivery of health infrastructure projects. It also results in health infrastructure projects which are more operable and maintainable; consequently it causes a faster and more economical operation and maintenance implementation.

The findings of this research will be shared with the interested participants in the form of a report.

RISKS

There are no risks beyond normal day-to-day living associated with your participation in this project.

PRIVACY AND CONFIDENTIALITY

All comments and responses will be treated confidentially and will be made anonymous when transcribed.

A digital recorder will be used to record the interview session. A transcript of the meeting discussions will be sent to the participants for verification. The recordings will be destroyed at the end of the project.

CONSENT TO PARTICIPATE

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

QUESTIONS / FURTHER INFORMATION ABOUT THE PROJECT

If you require any further information about the project, please contact one of the research team members named above.

CONCERNS / COMPLAINTS REGARDING THE CONDUCT OF THE PROJECT

QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Unit on 3138 5123 or email ethicscontact@qut.edu.au. The QUT Research Ethics Unit is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

Thank you for helping with this research project. Please keep this sheet for your information.

Queensland University of Technology Brisbane Australia	CONSENT FORM FOR QUT RESEARCH PROJECT

Extension of Constructability to Include Operation and Maintenance for Health Infrastructure Projects

QUT Approval Number 1100001558

RESEARCH TEAM CONTACTS

Principal Researcher:	Ehsan Saghatforoush, PhD Candidate, QUT	0432 397 900	e.saghatforoush@qut.edu.au
Associate Researchers:	Bambang Trigunarsyah, Assoc Prof, QUT		bambang.trigunarsyah@qut.edu.au
	Paul Xia, Lecturer, QUT		paul.xia@qut.edu.au
	Eric Too, Lecturer, USQ		eric.too@usq.edu.au

STATEMENT OF CONSENT

By signing below, you are indicating that you:

- have read and understood the information document regarding this project
- have had any questions answered to your satisfaction
- understand that if you have any additional questions you can contact the research team
- understand that you are free to withdraw at any time, without comment or penalty
- understand that you can contact the Research Ethics Unit on 3138 5123 or email ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project
- understand that the project will include audio-recording
- agree to participate in the project

Name ____

Signature ____

Date ______________________

Please send this Consent Form to:

Email:
e.saghatforoush@qut.edu.au

Ehsan Saghatforoush
Science and Engineering Faculty
Queensland University of Technology
2 George Street
GPO Box 2434
Brisbane QLD 4001

Appendix D
Fully-Structured Interview Questions

To what extend do you agree with the following statements?

Principles	*Statements*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Integration	1. Operability and maintainability must be an integral part of the project plan, as well as constructability practices.					
	2. Participation of O&M stakeholders in the masterplan review process updates the old Australian guidelines.					
	3. Integration of operability and maintainability concepts in design phase user group sessions eases O&M disparities.					
O&M Standards Definition	4. Definition of minimum standards by the Queensland Health during the planning phase prevents unnecessary future changes in the management of health infrastructure projects.					
	5. Standardisation of project documentation during planning and design phases balances O&M costs versus construction costs.					
Program	6. An overall realistic and O&M-sensitive program enables access to governmental funding support.					
	7. An overall realistic and O&M-sensitive program enables clearer anticipation of future needs of the health infrastructure.					
Team Skills	8. Multi-disciplinary consultations allow the incorporation of O&M skills into the planning phase.					
	9. Consideration of different technical construction, operation and maintenance skills within the planning phase enhances the planning processes.					
	10. Collecting information from O&M staff in local healthcare networks provides up-to-date O&M considerations in the planning and design phases.					
Accessibility	11. A healthcare centre with separate access paths for patients, staff, ambulances, visitors, etc facilitates faster attendance to services by O&M personnel.					
	12. Having an O&M oriented business solution design provides a better accessibility for O&M staff.					
Adaptability and Flexibility	13. Health infrastructures should be future proofed to minimize adaptation costs.					
	14. Involvement of O&M staff in user group sessions minimizes the number of inflexible designs.					
	15. If a project is designed flexible enough, it will prevent many of periodical services and facilities' changes in response to vast medical technological changes.					
Authority	16. Involvement of O&M staff with enough authority at the design or construction phases allows useful inputs from O&M perspective.					
	17. Use of experienced maintenance managers in project design and management offices can prevent future maintenance issues.					
Available Resources	18. Technology of design solutions should be matched with available materials, equipments and resources.					
	19. Understanding of latest technology and materials used in O&M of health infrastructures facilitates better design.					
Cleanability	20. Participation of actual healthcare projects' cleaners into user group sessions helps designers to have a better understanding of ongoing cleanability problems.					
	21. Right selection of materials and resources during the design plays a significant role in proper cleanability of healthcare buildings.					
Engineering Methodology	22. Having a cost effective engineering design facilitates achieving the projects with lower O&M costs.					
	23. Having a comprehensive guideline covering all engineering methodology aspects of O&M helps designers to design for the right engineering method.					
Functionality and Fit for Purpose	24. Understanding project purposes should be clarified right from beginning of the planning phase.					
	25. Making the designs to be based on actual project needs through proposing a functional planning and design brief is necessary.					

O&M Knowledge	26. O&M knowledge transfer into early design phase causes widening of business solution designs.					
	27. O&M knowledge transfer into early design phase prevents poor trainings and as the result stops under-engineered maintenance process.					
Specifications	28. Proper identification of projects' specifications plays an important role in correct locationing, building and delivering health projects.					
	29. Unless you have defined right specifications for your project, you won't achieve the right materials.					
Technical Leaders	30. If a health project is fully led ONLY by the architects, it will cause many technical problems for O&M staff.					
	31. It is important to make the project leading process like a team approach including both technical and architectural professionals rather than having a project fully led by the architects only.					
Hand Over & Trainings	32. Doing a proper final check up by an experienced maintenance staff just after the construction phase helps to have an appropriate hand over of documentations and manuals.					
	33. Doing a proper final check up by an experienced maintenance staff just after the construction phase prevents poor construction phase implementation, and results in fit for purpose projects.					
Feedback	34. O&M feedbacks should frequently be given to the designers in order to make facilities and designs more patients focused.					
	35. Feedbacks should not only be taken after finishing the construction phase; however there is a significant need to trace the feedbacks in longer periods because services will mostly be out of warranty starting after 2 years.					
Technology Absorption	36. Use of technology and computerisation along the construction, operation and maintenance phases should be maximised in order to improve patients' care system.					
	37. A consistent maintenance management system results in a cheaper and more systematic maintenance process.					
	38. Use of alternative innovative methods along the construction, operation and maintenance phases results in significant savings in total project life cycle costs.					
Corporate objectives	39. Constructability will be enhanced if the project team gain an understating of the clients' both corporate and project objectives.					
External Factors	40. External factors can affect the cost/or program of the project.					

Appendix E
Job Titles of Respondents

- ✓ Managing Director – Engineering Department
- ✓ Acting Principal Advisor – Sterilising Program Manager
- ✓ Manager – Facilities Development
- ✓ Director – Business Development
- ✓ Project Manager – Engineering Department
- ✓ Manager –Infrastructure Project Team
- ✓ Regional Manager – Building and Engineering Maintenance Services
- ✓ Director – Infrastructure Development and Delivery
- ✓ Principal Project Manager – Infrastructure Development and Delivery
- ✓ Director – Corporate Support Services
- ✓ Site Manager – Biomedical Technology Services
- ✓ Senior Cost Planner – Contractor Company
- ✓ Technical Director – Designer Team
- ✓ Project Designer – Architectural Team
- ✓ Service Engineer – Designer Team

Appendix F
Case Study Protocol

INTRODUCTION

A. Role of the Protocol

This case study protocol is to provide the procedures on individual tasks which are going to be undertaken in current research project, although details may vary. It shows how the researcher intends to answer the research questions, and do the adjustments in case of any probable changing circumstances.

AN OVERVIEW OF CASE STUDY

B1. Case study objectives: The case study method is used to:
(1) identify current Operation and Maintenance (O&M) issues of infrastructure projects.
(2) find existing practices in addressing them during the delivery phases.
(3) identify the determinants for effective and efficient implementation of operability and maintainability. It leads to some approaches that feed the O&M information into planning and design phases.

B2. Theoretical framework: This research will investigate current O&M issues, found in literatures, in order to come up with a new extended constructability model which covers post construction stages of Project Life Cycle (PLC) as well as pre-occupancy phases.

B3. Case study investigation questions: Current research case study questions are designed in order to answer main research project questions. A WBS technique was used to break the main questions into smaller ones. Then a review of the questions was implemented and as the result more detailed questions, written in lay language, are designed as below:

To Identify O&M Issues:

1. What are the issues you encounter during O&M phases?

To Address O&M Issues / To Identify the Approaches:

2. How do you address these issues?
3. Do you use any specific approach to face these issues?
4. What are the difficulties faced in carrying out this approach?
5. Do you foresee any alternative way for it?
6. On what basis do you recommend it?
7. How can this approach confront these issues?

Current

Difficulties

Potential

To Consider O&M Issues in Planning and Design Phases:

8. Can these approaches be achieved by feeding the O&M info into planning and design phases?
9. Who should be involved in planning and design? (You or anyone else?)
10. How can such involvement in planning and design satisfy these approaches?
11. To what extend can such involvement cause achievement of these approaches?
12. How can such involvement in planning and design phases be facilitated?
13. What do you reckon are the benefits of this involvement?

B4. Confidentiality: All comments and responses will be anonymous and will be treated confidentially. The names of individual persons are not required in any of responses.

B5. Recording and storage method: A digital recorder will be used to record the interview. A transcript of the interview will be sent to the respondents for verification. All data will be stored in researcher’s personal academic storage space within Queensland University of Technology area only.

B6. Benefits to participants: It is highly expected that this project findings will benefit health infrastructure project owners by designing a model which will eliminate/reduce project reworks during the O&M phases. Consequently, significant savings in the whole PLC costs is expected. The research findings will be reported to the participants as the benefit of their involvement in this research.

INTERVIEW SESSIONS’ TIMING

Phase 1 - Starting Phase: Introduction to the research (5 mins)

- Introduce myself and the research
- Ensure confidentiality and provide ethics consent form for signature

‘QUT has strict policy on ethics, and in order for this research to be carried, ethics had to be approved. That’s why before we start the interview I would like to ensure you that this interview is absolutely confidential, and in no way it could be apparent that responses came from you. Could you please read and sign this consent form to confirm your agreement to participate.’

- Ask for permission to record the interview

Phase 2 - Body Phase: Case Study Investigation Questions (40 mins)

- Questions are available in section B3.
- Asking for any available brochures or documents.
- Asking for any probable observation chances for better clarification of the issues.

Phase 3 - Closing Phase: Check Possibility of re-contacting (2 mins)

- Check with respondents if there is a possibility to contact them again in case any clarification is required.

DATA COLLECTION PROCEDURE

C1. Selection of cases of research: This research is designed to focus on those multi-faceted social infrastructure projects with more complicated O&M phases. That is why health centres within Queensland State, preferably nearer to Brisbane city, are the main targets for selection of cases. They include hospital buildings, medical centres, pathology centres, laboratories, etc.
The ‘participant information’ and ‘consent’ forms will be emailed to the participants prior to the interviews in order to get their permission. These forms will firstly be emailed to the target health infrastructure projects and then it will be requested to forward the email to any professionals within organisations who might be working on their O&M or facilities management departments. Initial contacts will be done using one of QUT students who is working in Queensland Health.

C2. Data collection method: As mentioned earlier, interview is the selected method of data collection in this research. The semi-structured list of questions is prepared to be used during the interviews.

C3. Interview timeframe: The needed data will be collected using interviews between February to April 2012. To have a detailed timeframe for it, there is a significant need for having initial discussions with target participants which will be performed when ethical clearance process is done.

C4. Definition of terms used in interviews: The participants are supposed to be selected from the professionals working in O&M of Queensland health infrastructure projects which are supposed to be familiar with many complicated terms; however the interview questions are designed in a way that there is no specific term that needs to be defined for the respondents.

C5. Preparation and ethical clearance: The needed forms for ethical clearance process will be filled up before end of 2011 and it is anticipated that the approval of ethics office will be taken by early February 2012 which is the start point for data collection process.

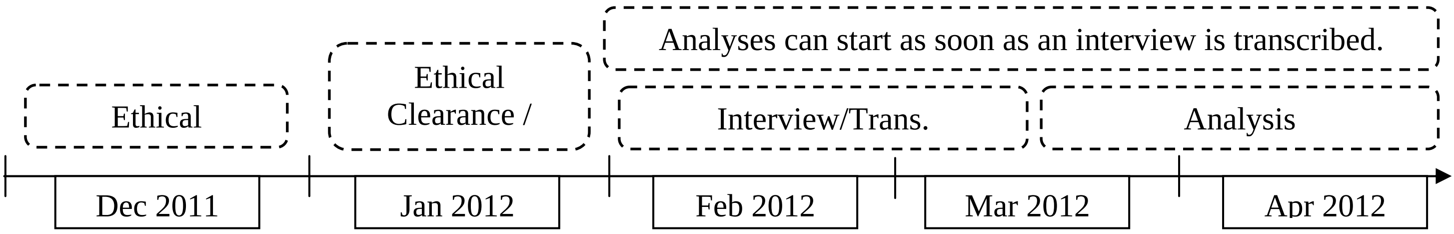
C6. Dealing with incomplete or interrupted interviews: After implementation of the first interview with the pilot case and verification of the interview questions and analyses, study of the other cases is supposed to be implemented parallel to each other, so in case of any problem during the interview sessions, another session needs to be replaced.

DATA COLLECTION PLAN

D1. Name of sites to be visited including contact persons: Based on initial discussions, this research will collect needed data by having series of interviews with O&M/facilities management sections of the 3 to 5 health centres within Queensland State. They include (1) Toowoomba Hospital, (2) Townsville Hospital, (3) Gold Coast University Hospital, (4) Royal Brisbane & Women Hospital, Hospital Infrastructure Development & Delivery Organisation and (6) CHIRSP centre. Toowoomba and Townsville Hospitals are quite older cases, compared with the others. Gold Coast University Hospital is an under construction case which satisfies the comments taken from Dr. Keith Hampson during CoC session. Maintenance manager of this hospital has been involved in planning, design and currently in its construction phase which is exactly what is needed in my research project. CHRISP is a centre for healthcare infection surveillance and prevention of Queensland hospitals. Participants from this centre can provide strong responses to biological, environmental and some managerial related questions of this research.

D2. Interviews Plan: Semi-structured interviews will be proposed.

- Participants: Target participants might be from each Facility Management or O&M Management people working in healthcare projects, or the corporate section of Queensland Health including Asset Management or CHIRSP, etc.
- Duration of each interview: 45-50 mins
- Schedule: Researcher plans to do the interviews in soonest possible time between February to April 2012.



D3. Preparation Prior to Site Visit:

- Digital recorder checking
- Review of case study investigation questions

D4. Case Study Report:

1. List of people interviewed
2. Reference to investigated documents
3. Reference to any observation

Reference to any special exploration or needed follow ups

Appendix G
Assembly of Problem Codes to Determine Matching Pattern Codes

Descriptive Coding

- Poor access to the facilities
- Disruption for medical treatment processes
- Not serious consideration of accessibility

⇨ Pattern coded as: **Improper Accessibility**

Descriptive Coding

- Lack of integration with older buildings
- No plan for future high technology facilities
- Lack of adaptation with older measurement units
- Lack of flexible designs
- Lack of functional or fit for purpose designs
- No consistent materials and equipment selection

⇨ Pattern coded as: **Lack of Flexibility /Adaptability**

Descriptive Coding

- Complexity of projects and designs
- Complexity of manuals
- Unproven or untested designs and technologies
- Increasing complexity of maintenance strategies

⇨ Pattern coded as: **Complexity**

Descriptive Coding

- Poorly cleanable designs
- Carpeted areas causing hygienic problems
- Low level of infection control standards

⇨ Pattern coded as: **Cleanability Problems**

Descriptive Coding

- Changing safety instructions
- Safety constraints
- Carpeted areas causing harms to staff’s safety

⇨ Pattern coded as: **Safety Issues**

Descriptive Coding

- No brands and model standardisation
- Lack of standard storage spaces
- Lack of consistent maintenance management system
- Use of out of date Australasian facility guidelines
- No unique system to manage ongoing changes
- No consistent materials and equipment selection
- No brands and model standardisation

⇨ Pattern coded as: **No Effective Standardisation**

Descriptive Coding

- Conflicting opinion in design
- Mental frames in user group sessions
- Unclear decision making process
- Maintenance staff literacy problems

⇨ Pattern coded as: **Inefficient Communication**

Descriptive Coding

- Poor implementation
- Poor training
- Under-engineered maintenance
- Some corporate section staff with no maintenance experience
- Governmental announcements with no planning behind
- Fast political changes
- Bureaucrat decision makers
- Maintenance concerns as discretion area
- Clinicians with no building understanding

⇨ Pattern coded as: **Poor Knowledge**

Descriptive Coding

- Increasing maintenance costs
- Low budget
- Unsustainable market condition
- Expensive early involvement of O&M professionals
- Underestimation of maintenance costs

⇨ Pattern coded as: **Budget Constraints**

Descriptive Coding

Incomplete construction docs or manuals

Late designs

Late consideration of maintenance issues

Poor project handover

Pattern coded as:

Late or Incomplete Handover of Documents

Descriptive Coding

No preventive maintenance program

Human resources problems

Limitation of equipment and materials

Pattern coded as:

No Preventive Programs

Descriptive Coding

Contracting problems

Changing legislations

Underestimated decisions made by politicians

Pattern coded as:

Legislations and Contracting Defects

Appendix H
Assembly of Current Practice Codes to Determine Matching Pattern Codes

Descriptive Coding

- Capacity study
- Planning prioritisation
- Having procurement team to select builders

⇒ Pattern coded as: **Early Programming**

Descriptive Coding

- Having master planning consultations
- Proposing Workshops within AMSU
- Having a business solution designs
- Use of OMTRAK software
- Streamlined instruments management system
- Use of computerised maintenance management system

⇒ Pattern coded as: **Standardisation**

Descriptive Coding

- Identification of O&M problems to executive members
- Proposing panel of providers in planning stage
- Use of multidisciplinary consultation sessions
- Proposing user group session in design stage

⇒ Pattern coded as: **Knowledge Sharing**

Descriptive Coding

- Use of BIM (Building Information Modelling) software
- Use of TS11 (NSW based and designed)

⇒ Pattern coded as: **Integration of Knowledge**

Descriptive Coding

- Final Checkups after construction stage
- Regular supervision, inspections and quality controls

⇒ Pattern coded as: **Control of Handover Stage**

Descriptive Coding

Having a maintenance unit in construction site

Getting involved in construction management team's decisions

Interaction with builders

Using contractors under warranty

Pattern coded as:

Strengthening Communication

Descriptive Coding

Preparation of high quality maintenance manuals

Proposing extra training for maintenance staff

Pattern coded as:

Developing Knowledge and Experience

Descriptive Coding

Compromisation of maintenance and medical needs

Regular retrofitting

Regular testing of the equipment

Pattern coded as:

Regular Monitoring

Descriptive Coding

Seeking money from people who initially made a service

Skim and optimising to create storage areas

Use of alternative innovative methods

Use of alternative materials

Pattern coded as:

Controlling the Costs

Descriptive Coding

Removal of dangerous materials like Asbestos

Removal of useless materials like carpets

Pattern coded as:

Safety Considerations